THE VISITOR EXPERIENCE USING AUGMENTED REALITY ON MOBILE DEVICES IN MUSEUM EXHIBITIONS

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DOCTORAL PROGRAM IN DIGITAL MEDIA

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ABSTRACT

This research addresses the compelling need of the modern museum to understand its audiences, their preferences and responses to technology mediated experiences. The focus is on Augmented Reality (AR) technology delivered through mobile devices in antiquated museum exhibitions as one approach to repairing the gap in visitor expectations and their actual experiences in such exhibitions.

The investigation took place at the Bone Hall, a vertebrate skeleton exhibition at the Smithsonian's National Museum of Natural History, unchanged since the 1960s and no longer meeting visitor expectations for engagement and interactivity.

A mobile app called Skin & Bones was developed to reinvigorate the Bone Hall. It features 13 of the animals on display and includes 10 AR pieces of content, 32 videos and four activities. The content and structure of the app were designed according to the IPOP theory of experience preference, a four-dimensional construct that proposes museum visitors vary from one another in their relative attraction for Ideas, People, Objects and Physical activities.

The research adapted a UX framework developed for evaluating the user experience with mobile AR services and combined it with traditional visitor studies' approaches such as observation and tracking, questionnaires and interviews. For research purposes, two versions of the app were developed to isolate AR as a variable and to collect individual user actions. App analytics provided information on how onsite and offsite users' behavior differed.

The findings of the research confirm the positive influence of AR technology over the Visitor Experience as reflected in increased engagement with the content on display and shaping of app content viewing and preferences. The analysis of all study variables associated greater viewing of AR with higher levels of satisfaction and surpassed expectations. The technology was shown to promote the most emotional and instrumental experiences, and the least social experiences. Visitor engagement increased to the level of another gallery in the same museum designed anew 40 years later.

The research also contributes to testing the predictive power of the IPOP framework and provides guidance in the adoption of AR technology and development of mobile augmented tools for indoor museum exhibitions and offsite use.

KEYWORDS

Visitor Experience, Augmented Reality, Museum Exhibitions, Mobile Museum Technology.

RESUMO

Este estudo aborda a necessidade de o museu moderno compreender os seus públicos, quais as suas preferências e como reagem a experiências mediadas pela tecnologia. Concentra-se na tecnologia de Realidade Aumentada (RA) desenvolvida para dispositivos móveis a utilizar em exposições de museu antiquadas como uma forma de melhorar as experiências dos visitantes.

O estudo decorreu no *Bone Hall*, uma exposição de esqueletos no Museu Nacional de História Natural do Instituto Smithsonian, que não sofria alterações desde os anos 60. A exposição tinha deixado de corresponder às expetativas dos visitantes que procuravam mais envolvimento e interatividade.

Com o objetivo de revitalizar o *Bone Hall* foi desenvolvida uma aplicação móvel denominada *Skin & Bones*. Representa 13 dos animais em exposição e inclui 10 experiências de RA, 32 vídeos e quatro atividades. Os conteúdos e estrutura da aplicação obedecem à teoria de preferências IPOP a qual propõe que os visitantes são atraídos em proporção diferente por conteúdos sobre ideias, pessoas, objetos e atividades físicas.

Os métodos de investigação incluíram a adaptação de um procedimento previamente desenvolvido para estudar a Experiência do Utilizador com serviços móveis aumentados e também métodos tradicionais no estudo de visitantes, como a observação e rastreamento, questionários e entrevistas. Foram produzidas duas versões da aplicação móvel para isolar a RA como variável e recolher dados sobre as escolhas dos participantes. Uma ferramenta de dados analíticos móveis forneceu informações sobre a utilização dentro e fora do Museu.

Os resultados confirmaram o efeito positivo da RA sobre a Experiência do Visitante, através do aumento do interesse e visionamento, e preferência por conteúdos aumentados. A análise conjunta de todas as variáveis do estudo revelou a ligação entre um maior consumo de RA, níveis de satisfação mais elevados e superação das expetativas. Demonstrou-se que a tecnologia promove sobretudo experiências emocionais e instrumentais e menos experiências sociais. O interesse dos visitantes aumentou para o mesmo nível do registado noutra exposição do mesmo museu contruída de raiz 40 anos depois.

O estudo testou ainda a capacidade preditiva da teoria IPOP e fornece orientações sobre a adoção de RA e sobre o desenvolvimento de aplicações móveis aumentadas para utilização nas exposições do museu e fora dele.

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I. INTRODUCTION

A significant part of the strategic planning of today's cultural institutes includes understanding and improving the Visitor Experience – what motivates individuals to go to a museum, which factors influence their satisfaction with the visit, what it is that visitors retain, how overall to improve the various ways visitors benefit from their visits. This institutional drive and focus on the visitor is the result of a complex and much discussed attitudinal departure from the established collection-oriented, top-down approach, that used to guide museum practices. Museums were led to transform themselves by familiar modern pressures such as the decline in public funding, increased reliance on donor and ticket revenues, weakening in audience numbers, among others. Facing such reality, museums recognized that to be a meaningful part of society and make significant contributions to the cultural development, education and ethos of individuals – values that have always demarcated cultural institutions – understanding visitors to their core and within a cultural context is a necessity.

The conceptualization of the Visitor Experience is an ongoing process and the subject has proven to be intricate, and as complex as the diversity of human beings. There is an understanding that previous experiences, gender, age and many other factors contributing to the differences and diversity of human nature ultimately shape the outcome of an individual's visit to a museum. Some of the identified factors are personal (including visitors' existing expectations and preferences), social (related to the human connections during the visit) and physical (concerning the space and the content of the exhibitions).

This holistic and multifaceted reality of the Visitor Experience is challenging to museum professionals who primarily have a direct influence on the physical space, less often on the social context and never on the personal background. Museums continuously explore new ways to improve the Visitor Experience and revise the traditional ways of presenting the collections and information, expanding their current practices.

The challenge is greater at institutions with a long history and established conventions. Here, exhibitions tend to age and become outdated, even if the collections displayed preserve the original educational and historical value. Multiple aspects of an exhibition contribute to the overall Visitor Experience from the architecture to the design, to the mechanisms used to communicate, and if these mechanisms are not handled well, they can detract and have a negative effect. Particularly in a technology-saturated age that fosters constant renewal of information, it is challenging for institutions to keep abreast and maintain their offerings suitable to modern visitor expectations, and simultaneously be true to the core values and analog collection assets that define them. Restoring entire galleries is seldom an option considering the multiple year endeavor and the effort of circumventing institutional bureaucracies and fund raising constraints. Coordinating the sizeable number of professionals involved in exhibition projects, including curators, designers, developers, evaluators, funders, stakeholders and marketers, is an additional challenge. The historical preservation of buildings and subject areas that may have special interest groups and niche audiences are occasionally further reasons that hold renovations back.

The research presented in this dissertation considers such museum settings, exhibitions that have fallen out of grace due to their age, subject or approach to a subject, and examines the influence that a particular technology, Augmented Reality (hereinafter referred to as AR), can have on the Visitor Experience within obsolete exhibitions.

AR has been the subject of experimentation by museums since the early 2000s, with promises of transforming the traditional mode of interaction between visitors and collections. Its main feature of superimposing virtual content onto the surrounding physical environment, has the potential to merge the observational and interpretational aspects of experiencing an object or a cultural site. AR possibly overcomes some of the limitations of an exhibition space by introducing up-to-date content, delivered in a novel and captivating way, without the need for a physical renovation, thus being a resource-minded tool. It also affords the coexistence of the antiquated and contemporary, providing flexibility to suit different audience preferences, and does not compromise the emphasis on the museum collections, as the virtual overlay is dependent on and connected to the tangible exhibition.

By adding AR and studying the Visitor Experience in such an exhibition, one that through neglect was frozen in the past, this research reflects on the temporal and spatial tensions that are exposed in museums today when 21st century technology and disruptive museum practices are revitalizing spaces and replacing traditional methods as a way to respond to visitor expectations. Moreover, the research contributes to a better understanding of modern museum audiences and their preferences for and aptitudes with technology mediated experiences. This research is a response to today's museum agendas that place visitors first in their priorities and it is an attempt to lessen the gap that exists for empirical studies in museum literature to guide the field of museum practitioners. Despite the wide acceptance of AR technology, few in depth assessments have been made about its influence on visitors, and there is limited information that museum professionals can rely on to guide their decisions. Commonly, the case studies published and presented at professional conferences report on implementation and usability, and few consider the effect of the experiences they create on the visitors.

This research spans the design, testing, development, implementation, and the effects on visitors using an AR mobile app within an antiquated exhibition on skeletons in a natural history museum. Whereas the current displays were installed in the 1960s, some of the specimens were already on public view in the 1880s. The absence of institutional resources and lack of interest in modernizing the exhibition, given its historical and perceived educational value, led to its untouched senescence. Casual observations indicated that it was no longer, if ever, meeting modern visitors' expectations for interactivity and interpretation. The decision to alter or repair the Visitor Experience using mobile AR was a conscious choice that consequently preserved the historic exhibition as the technology can be used without altering the physical space.

The study was designed to examine visitors to the exhibition before and after the digital intervention to understand the contribution of the technology to visits in an otherwise untouched exhibition. Additionally, for research purposes, the app was developed in two versions, one with AR and one without, which isolated AR technology as a variable in the study for its influence on the Visitor Experience. The design of the research is laid out in Chapter III (p.45), and the results obtained are presented and discussed in Chapter IV (p.91). Chapter V (p.147) draws a conclusion to the research findings.

The referred chapters are preceded by a literature review, included in Chapter II (p.5). First, the review includes the published work of different authors on the conceptualization and analysis of Visitor Experience research, and attempts to demonstrate how their frameworks parallel those used to learn about the User Experience (UX), a distinct field of knowledge born out of the research on human-computer interaction. This research adapts frameworks from both museums studies and UX studies, which is covered in depth in Chapter III.1 (p.45).

Second, the literature review describes the current state of embedding interactive technologies in museum settings, the controversy that it generates, the visitor response to the digital tools, and the intentions and decision-making process of museum professionals when employing such tools.

Third, the literature review centers on AR technology. It provides a global perspective on the origins, evolution and current use and acceptance in the museum landscape. A selection of examples is used that represent the different categories of AR applications; one of those applications – the use of the technology to reinvigorate antiquated exhibitions – is the principal focus of this research.

The review also identifies two implementation models for AR applications in museums and categorizes the selected examples according to the models. Furthermore, some concerns and challenges are described regarding the adoption and production of AR mobile applications in museums that surface across the literature. The purpose of covering these subjects is to contribute a perspective on the practical aspects of AR adoption in museums and to use the research data in this project to test the literature assessments and assumptions.

Finally, the literature review comprises a description of some relevant research studies about AR technology that have been conducted in museum settings that justify and contextualize this research.

II. LITERATURE REVIEW

1. VISITOR EXPERIENCE

During the past 30 years museums of all kinds have tried to attract and become more responsive to the interests of a diverse public (E. Alexander & Alexander, 2007; Anderson, 2012; Black, 2012; Weil, 2002), and are shifting focus from being object-centered institutions towards visitor-centered institutions (Hein, 2000). The main motivations for the fundamental transformation are the drop in public funding leading to increased reliance on donor and visitor ticket funds (Ballantyne & Uzzell, 2011; Goulding, 2000), decline in museums audiences (Simon, 2010), accountability from professional museum associations that give accreditation and establish guidelines (Shettel, 2008), and a new attitude toward collections, reconsidering what constitutes the best form of engagement with a museum exhibition (e.g. experiencing objects interactively versus passively) (Hein, 2007).

Museum professionals realized there was a gap between theirs' and the visitors' perspectives (Korn, 1992) – "learning", the poorly defined (Kelly, 2007) but ultimate goal that exhibitions tried to afford is in fact limited when expected as a single outcome, because visitors seek and obtain several other beneficial outcomes (Masberg & Silverman, 1996; Packer, 2008). The term was even demoted in favor of "meaning-making", the innate human motivation that should be stimulated (Falk & Dierking, 2000; Rounds, 1999; Silverman, 1995). Exhibitions were found to be somewhat deficient and ineffective methods for communicating or changing attitudes, considering that visitors respond mostly to exhibitions and themes that are personally relevant and with which they can easily connect; exhibitions seem however to be influential in confirming, reinforcing and extending existing beliefs (Doering, 1999b).

The new positioning of visitors at the heart of institutional strategic planning means they have to be taken into account in every step, from architectural layout to exhibition design. This transformation was accompanied and exacerbated by the pervasive and global introduction of technology onto museum internal operations and services to the public, which can profoundly change the connection of visitors with the institutions and their offerings[1]. This elicited a primary need to meet and understand audiences, their motivations to go to museums, and the factors that influence their satisfaction during a visit (Kirchberg & Tröndle, 2012; Miles, 2007; Shettel, 2008). A new set of terms became part of the lexicon of museum professionals – Visitor Experience – which only recently was defined by Packer and Ballantyne (2016) as *"an*

[1] This topic is the subject of the next section (p.11).

individual's immediate or ongoing, subjective and personal response to an activity, setting or event outside of their usual environment." (p.133).

Today, the efforts to comprehend the Visitor Experience are no longer new, but are far from reaching maturity. As the review by Kirchberg and Tröndle (2012) noted, "*the bulk of museum studies literature concerns cultural, historical, or critical analyses of the museum as an institution: its societal role, its politics and management issues, its function as a place for learning, leisure and self-actualization, and its curatorial and collecting issues. Rarely are the experiences of museum visitors a focus of interest.*" (p.436). The somewhat recent paradigm shift and the difficulty in securing the resources required (i.e., time, money and specialized staff) to conduct such studies (Shettel, 2008) explain the literature gap. This reality comes across even more in the context of the application of technology in museums (Pallud & Monod, 2010), considering the breadth of applications and more recent and profound developments.

However, there is an unsuspected and apparently unrelated field of knowledge that may serve as inspiration and make a beneficial contribution to the study of the Visitor Experience – the User Experience (UX) within the research on Human-Computer Interaction (HCI) (Pallud & Monod, 2010). HCI, as the name indicates, concerns the design and use of computer technology at the interface of users and computers, with UX having an emphasis on the human experiential feelings and preferences.

The affinity between Visitor Experience and UX is mainly pertinent in museum settings where technology is prevalent and plays a major role in facilitating the connection of visitors and the collections on display, which is a recurrent situation in today's institutions. With the integration of computers, mobile devices and overall interactives into the museum exhibition space, previously inexistent conflicts developed as the offspring of the new ways to mediate experiences. The technology, even when aiming for transparency, can be more complex than the content it carries, it can divide the user's attention, and create a one-to-one linear interaction between visitor and machine where there used to be co-participation between visitors (Tost & Economou, 2007). Thus the Visitor Experience in such machine-mediated contexts, although not new, is understudied and understanding the interactions and outcomes is evermore relevant.

Here it is illustrated how the UX, similarly to the Visitor Experience, rose out of the need and interest in understanding the human dimension, and how both fields encompass parallel frameworks.

The interest in UX grew exponentially, both within academia and industry, when researchers and practitioners became aware of the limitations of the traditional HCI usability frameworks that focus largely on user cognition and user performance (Law, Roto, Hassenzahl, Vermeeren, & Kort, 2009). As they realized productivity or learnability are not the only factors of importance in digital design, the person's experience has to be taken into account; hence the need to be more encompassing than just ensuring the product's instrumental value (Hassenzahl

& Tractinsky, 2006). By concentrating on the UX, researchers and practitioners redirected their attention to the non-utilitarian aspects of the interaction, considering users' affective behaviors, sensations, aesthetic preferences and the value of the interactions with a product or a system.

Given the inherent subjectivity of the UX, some authors describe it through a collection of definitions rather than by a single one (Roto, Law, Vermeeren, & Hoonhout, 2011). However, some key points are shared by most, e.g., the fact that it is inherently personal and affected by the "*user's internal state (predispositions, expectations, needs, motivation, mood, etc.), the characteristics of the designed system (e.g. complexity, purpose, usability, functionality, etc.) and the context (or the environment) within which the interaction occurs (e.g. organizational/social setting, meaningfulness of the activity, voluntariness of use, etc.).*" (Hassenzahl & Tractinsky, 2006, p.95).

Just as the UX concerns the interaction between a user and a digital product or a service, the Visitor Experience pertains the interaction between the visitor and the products and services provided by the museum. The museum product is delivered in a physical environment that is defined by its layout, lighting, means of orienting the visitor, queues, etc.; and its service is conveying information and engaging with the visitor by resorting to methods that stimulate interest (Goulding, 2000). The delivery of the museum service can be described as the selling of an experience (Bateson, 1991, cited by Goulding, 2000). In fact, Doering (1999b) advocated for museums to treat visitors as "clients" (as opposed to strangers or guests), by being accountable and acknowledging the responsibility to understand and meet their needs and expectations.

Walls, Okumus, Wang and Kwun (2011) discussed how providers can only generate opportunities for the experiences. Museums can create the physical and social environments or circumstances in which visitors have an experience, but the experience itself takes place inside the individuals as their personal response to the encounter with the exhibition. Therefore Marty (2007a) said "*by understanding the information needs of museum visitors, museum professionals can better serve their clientele from a variety of perspectives.*" (p.7). These views, that are shared by other authors as well (Hooper-Greenhill, 1992; Masberg & Silverman, 1996; Weil, 2002) concern one of the paradigms that have been adopted to discuss, define and study museums, a paradigm hailing from the tradition and perspectives of market research (Peacock & Brownbill, 2007). The market research perspective has gained considerable notice possibly because it directs the attention to the expectations and behaviors of the visitors rather than to the museum's own products and agendas. However, views can be expected to swing like a pendulum over time with some progression toward a more synthetic view.

Forlizzi and Battarbee (2004) argue that "*what is unique to design research relative to understanding experience is that it is focused on the interactions between people and products, and the experience that results. This includes all aspects of experiencing a product — physical, sensual, cognitive, emotional, and aesthetic.*" (p.261). If, as mentioned above, the museum is considered to deliver a product to its audience, then researching the Visitor Experience in cultural institutions is not strikingly different than researching other experiences that involve interaction between users and products. Forlizzi and Battarbee (2004) set out to organize and better understand how the existing approaches to designing the UX for interactive systems – born from multidisciplinary sources – relate to each other. They realized that some take the perspective of the user, others attempt to understand experience as it relates to the product, and a third group tries to comprehend UX through the interaction between user and product.

The three categories parallel the general museum perspectives over time. Product-centered models align with museums' object-centered models, in providing straightforward applications for creating products/displaying objects that evoke compelling experiences. User-centered models help to understand the people who will use the products, through their actions and preferences, and align with visitor-centered models in museums. Interaction-centered models explore the role that products serve in bridging the gap between designer and user, and align with the somewhat recent movement that has gained relevance as a museum practice, called participatory culture. The same way that designers and users are getting closer to one another and UX is focusing on the positive outcomes of the interaction, so are museums and their audiences – there is an open invitation for visitors to become participants and not passive consumers of the museums' offerings (Simon, 2010).

In addition to the similarities in the operational approaches to developing and studying the UX and the Visitor Experience, individual frameworks in each field are analogous in the holistic human dimensions they consider.

Among UX frameworks that analyze the experience with products, the work by Desmet and Hekkert (2007) distinguishes three components – aesthetic pleasure, attribution of meaning and emotional response. Thus, for the authors, the experience prompted by the interaction between a user and a product is the collection of affective and cognitive responses that result from the satisfaction of the senses, the meanings and associations that are made, and the feelings and emotions that are elicited. Buccini and Padovani (2007) on the other hand, are more encompassing, consolidating the UX with a product in six categories: 1) experiences related to the senses which are instinctive and require low cognitive performance, 2) experiences related to the emotions which are subjective as emotions vary between individuals, 3) social experiences where the actions of others influence the individuals' experience, 4) cognitive experiences dependent on the users' aesthetic, semantic and symbolic interpretations, 5) experiences related to the usability and functionality of the products, and 6) motivational experiences when the product influences the user to perform a certain behavior.

Among Visitor Experience frameworks, the work of de Rojas and Camarero (2006) embraced a concept rooted in marketing concerns – consumer satisfaction. According to their study, a satisfying museum visit is dually dependent on the cognitive and emotional aspects perceived by the visitor. Satisfaction is recognized when the evaluation of the quality of the experience meets or exceeds the existing expectations, thus it is modulated by the individual's frame of mind before starting the visit. Satisfaction is also dependent on positive emotions associated with experiences early in the user's experience when expectations and reality are compared. To Packer and Bond (2010), satisfaction in the Visitor Experience is connected to the restorative effect that the visit may have in the individuals, particularly to frequent visitors for which museums can provide a sense of relaxation, peace and tranquility, or thoughtfulness.

Packer and Ballantyne (2016) in their review of the literature regarding the Visitor Experience additionally introduced four defining characteristics, highlighting that the Visitor Experience is 1) inherently personal and subjective, 2) responsive to the affordances of external activities, settings or events, meaning that it is constructed through the personal interpretation of those external contributions and therefore can be influenced but not controlled by the design of the physical context, 3) bounded in time and space, and 4) significant to the visitor, impacting her differently than the everyday life, either in a positive or negative way. The authors proposed a Multifaceted Model that can be applied to characterize the nature or content of the Visitor Experience by capturing 10 different facets: physical experiences, sensory experiences, cognitive experiences, emotional experiences, hedonic experiences, restorative experiences, introspective experiences, transformative experiences, spiritual experiences and relational experiences.

Doering (1999b) and Pekarik, Doering and Karns (1999) also considered the individual dimensions of the visit. Based on accumulated studies conducted at the Smithsonian Institution museums over the years using a variety of research methods, the authors constructed a list of 14 types of satisfying museum experiences, that were arranged into four categories: 1) object experiences (e.g. being moved by beauty, seeing rare/uncommon/valuable things, seeing "the real thing"), 2) cognitive experiences (e.g. "enriching my understanding", gaining information or knowledge), 3) introspective experiences (e.g. "reflecting on the meaning of what I was looking at", imagining other times or places), and 4) social experiences (e.g. spending time with friends/family/other people, "seeing my children learning new things"). The complete list was incorporated into questionnaires and they showed that visitors could easily identify their most valued experience. Doering (1999b) went further in saying that museums should design spaces to enhance and support each of the four categories of experiences.

Additionally, Doering (1999b) recognized that visitors carry with them an "entrance narrative", or internal storyline, which has three components: 1) a basic framework or the fundamental way that individuals interpret the world, 2) existing information about a subject, and 3) personal experiences, emotions and memories that support their understanding. They predicted that the most satisfying experiences are those that resonate with the visitor's entrance narrative and confirm their existing views and expectations (empirically confirmed by de Rojas and

Camarero years later). In fact, in the work of Jagger, Dubek and Pedretti (2012) the personal narrative of visitors in exhibitions with controversial subjects proved to be paramount to the experience and largely contribute to the meaning-making around the displays.

The personal narrative is also contemplated in the highly influential work of Falk and Dierking (2000). In the "contextual model of learning" in museums, they consider the visitor's personal context (the socio-economic predispositions and expectations), as well as the socio-cultural context and the physical context. In this framework, experiences delivered through technology, such as mobile devices, represent a part of the physical context of the visitor (Falk & Dierking, 2008). It is the product of the interaction of the three contexts over time, none of which are ever stable or constant, that constructs the individual's meaning-making in museum exhibitions. Given that the personal context – prior experiences, knowledge, motivations for visiting, interests – is so determinant, the authors believe that the physical context can only enhance the Visitor Experience if visitors can personally tailor the visit. In a technology-enhanced context, a well designed digital tool that is customizable, can assist visitors in meeting their needs and interests by layering multisensory elements that enrich the physical space. Such digital tools have the potential to improve the meaning made from the exhibitions and extend the Visitor Experience beyond the museum visit.

Even if some of these frameworks to study visitor needs and to provide guidance to museums have been empirically tested, and despite Falk's impressions on the positive contribution of technology, there is an absence of identified criteria that can be used to assess the Visitor Experience in technology-enhanced cultural contexts (Pallud & Monod, 2010). The conceptual similarities between the UX and Visitor Experience – especially the literature consensus that both go beyond usability and accessibility, that they comprise emotions and behaviors, and have a holistic multidimensional perspective of the factors that influence the experience (such as the individual's existing preferences and expectations) – validates an infusion of UX methods and applied frameworks to the study of the Visitor Experience in technology-enhanced museums.

This research adopted a UX framework particular to one kind of technology that has gained popularity within museums in the recent past, Augmented Reality (AR). This approach was combined with more traditional ethnographic methods in visitor studies to obtain well-rounded information to study the Visitor Experience with AR. This is further discussed in Chapter III.1 (p.45). The following section on museums and technology is a review of the literature concerning the adoption of technology by museums, and how it influences the experience of the visitors that come across digitally-mediated exhibitions.

2. MUSEUMS AND TECHNOLOGY

The transformations that museums underwent in the last 30 years, reflected in greater motivation and interest in understanding and conceptualizing the Visitor Experience, were accompanied in the second half of that period of time by internal alterations. Museum management responded to the varying demands of access and organization of information through the adoption of collection management systems and later through the digitization of collections (Marty, 2007a). Simultaneously, institutions recognized the importance of an online presence which motivated the creation of the first museum websites in the mid-1990s (Jones, 2007), and there was the adoption of other technologies to enhance the exhibitions. The infusion of technology was such that very few museums today exist without some form of interactives in their exhibitions, and it is increasingly rare for a visitor to have an entirely passive experience (Marty, 2007b).

What visitors come across more frequently is a range of new media technologies, from high definition video and animation, that include music and sound effects, touchscreens with games and 3D modeling manipulation, and a host of other interactive experiences (Gilbert, 2016; Lohr, 2014). Even if the basis of most exhibitions is still the conventional tool of storytelling, visitors are pulled into the stories through multisensory digital experiences that are as much about feelings and emotions as they are about knowledge and cognition (Pallud & Monod, 2010; Stogner, 2009).

Technologies have also promoted two new forms of museum experience: the media-enhanced onsite experience, which is immersive, experiential, multisensory; and the media-driven offsite experience, which is on demand and enables personalization and sharing of information (Stogner, 2009). What drives modern museum interactivity is integration where access to all types of resources becomes uniform, continuous and transparent (Marty, 2007b). Visitors recognize the digital connectivity and that is reflected in their discourse, their behaviors and in what individuals experience in museums (Kelly, 2016).

Depending on the subject of the museum, there may be different specific objectives for the use of interactives onsite, such as engaging in the direct experience and exploration of natural phenomena or concepts in science museums (Marianna Adams, Luke, & Moussouri, 2004), visualizing site reconstruction and contextualization in archaeology and history museums, or eliciting feelings and encouraging aesthetic contemplation in art museums (Jarrier & Bourgeon-Renault, 2012).

However, another more arching reason has been identified for the use of interactive technology – most museum professionals consider that using technological resources is inevitable. As a matter of fact, as Stogner (2009) points out, "*the issue is no longer whether to use media to enhance museum exhibitions, but how to use it.*" (p.385). On a mission to maintain existing audiences and attract new ones, due to budgetary constraints and funding that often depends on attendance levels, museum professionals accept that offering more entertainment and digital interaction, despite higher implementation costs, can ameliorate the problem (Balloffet, Courvoisier, & Lagier, 2014). The emphasis is frequently on enticing younger visitors who belong to a generation virtually connected, digitally native, and socially networked (Stogner, 2009). Still, there are those who see the flip side of using interactives as a marketing tool to appeal to certain target audiences, considering that they can be discouraging to a broader demographic or may reduce the appeal to some traditional audiences (Marty, 2007b; West, 2004).

An additional commonly voiced concern by museum professionals is that by presenting content in a contemporary interactive and entertaining style, some museums are contradicting their self-image and violating their established mission, leading to external confusion about the museum's motives and future directions (West, 2004). There is also an underlying idea that the educational mission is being undermined, at the expense of accuracy and real knowledge (Stogner, 2009), distracting visitors' attention from the primary focus, the collection objects (Marianna Adams et al., 2004). Museums that unreservedly endorsed technology have been likened to amusement parks, in a contrast between high culture (museum as a temple) and popular culture (amusement park for entertainment purposes only) (Balloffet et al., 2014). Lastly, some institutions, especially those in countries lagging behind the main current of development, have been accused of following trends, using new media to mask conventional practices and outdated philosophies (Šola, 2010).

But what is the visitors' opinion about interactives in museum exhibitions? Visitors seem to find interactive exhibitions meaningful, perceiving in them opportunities to communicate and socialize, receive personal feedback, and actively learn in an applied everyday fashion (Falk, Scott, Dierking, Rennie, & Jones, 2004). A study that took place both at a science center and at a history and science collections-based museum, demonstrated that interactivity was a major expectation in the former and less so in the latter, despite the museum's effort to be more engaging and interactive (Falk et al., 2004). But the study also showed that in the long term, visitors that had interactive experiences in the museum, changed their existing perception of the institution as "dry and dusty" to a place that was "modern" and "looked forward". The study additionally proved that interactives supported visitor learning and/or reinforced facts and concepts.

Jarrier and Bourgeon-Renault (2012) looked at several types of mediation devices in an art museum and found they elicit visitors' emotions differently. Study participants were the most positive about smartphones and tablets when compared to audio guides and interactive displays, which were perceived as outdated and monotonous, with content that was poor and incomplete. Smartphones and tablets were also preferred for being brighter, more readable and pleasurable to use, even if they can still inhibit emotions and aesthetic pleasure caused by dividing attention between the screen and the artworks.

A careful consideration of all the options of mediation devices currently available to employ in museum exhibitions was conducted by the team at the Cooper Hewitt, the Smithsonian Design Museum (New York), which they did during the three years that the museum was closed for renovation (Chan & Cope, 2015). The digital makeover was to accompany the physical renovation of the facilities and aimed at drawing broader, more diverse audiences, that would spend more time at the museum and return more often. The project became one of the most discussed in the recent history of technology in museums, and garnered attention from museum professionals, the news media and visitors alike.

Chan and Cope (2015) set out with some principles that included creating reasons for visitors to go to the museum physically rather than only digitally, but at the same time they did not want to hold back any available content from the web. They drafted concepts for the use of media and technology in the galleries such as encouraging visitors to play and fostering socially interactive experiences that did not require looking down at devices. There was to be a mechanism in conjunction with the web that the visitor could use to keep a record of the visit and preserve it, and the technology was to be ubiquitous throughout the museum. By distributing interactive experiences through all galleries they intended to convey the idea that technology was meant to be used by all visitors, not just the young and tech-savvy.

With these concepts in mind they opted out of developing a mobile app, fearing that it would interfere with the social experience and lead to a heads-down visit. Instead, they selected large interactive tables deployed across the museum where visitors can collectively browse the collection, access related media and explore the design process of the objects. At the tables visitors can also digitally create their own iconic designs of common objects such as a chair or a hat. Their solution was "The Pen". The Pen is a custom-made stylus-like device that is distributed at the beginning of the visit and not only functions as a drawing and browsing tool, it also allows visitors to record and save images of the objects and the label information associated with them. Any object that was touched with The Pen in the museum becomes available for later revisiting on the web as the visitor's unique collection. All in all, the authors documented the success of the intervention and witnessed the change of the relationship between the Cooper Hewitt and its visitors and saw a manifold increase in visitor numbers.

Another recent remodeling project involving media and technology famously took place at the Cleveland Museum of Art (CMA) and equally aimed at increasing visitors' connection with the museum's collection through interpretive technologies and design (J. Alexander, 2014; J. Alexander, Barton, & Goeser, 2013). Gallery One includes a 40ft (12.2m) interactive digital wall that dramatically visualizes all the works from the museum's permanent collection on display at the galleries, grouped according to different criteria; visitors can use it to explore, make connections between objects and read the related information. The Gallery also incorporates interactive kiosks meant for a closer look at the artwork. Just like the Cooper Hewitt, CMA centered the experiences on the visitors to empower them to create personal meanings with the collection, and to promote tools for critical observation and investigative methods driven by their interests.

These projects at the Cooper Hewitt and CMA reflect how new interactive technologies are transforming the experience of visiting a museum, to the point that is almost indistinguishable where the analog ends and the digital begins. Looking ahead, Parry (2013) introduced the concept of the "postdigital" museum to depict the blending and embedding of new media, where the boundaries between "digital" and "non-digital" have been dropped, and both are the norm that together unite the museum's objectives to its exhibition practices.

2.1. MOBILE TECHNOLOGY

Within the transformation elicited by the embedding of technology in museum settings, the particular case of mobile technology has gathered, in recent years, the most attention and heightened dialogues among museum professionals. Mobile technology – which currently is synonymous with visitors using their own smartphones and tablets in museum exhibitions, or more broadly using those devices offsite or on-the-go to take advantage of museum resources – is in fact one of the oldest forms of technology in cultural institutions. Dating back to the 1960s, the closed-circuit short-wave radio broadcasting systems that outputted to the portable radio receivers with headphones that visitors were carrying, comprised the first generation of gallery audio guides (Tallon, 2008). But unlike these radio systems that took visitors, in synchrony, from gallery to gallery, all listening to the same content and looking at the same displays, today's devices introduced not just a different medium, but also an entirely different approach (Parry, 2008).

The portable, light weight, computationally powerful and ubiquitous devices are new platforms for interpretative materials that accompany the visitor during and after the visit, and open a two-way communication channel that operates in real time (Damala, Cubaud, Bationo, Houlier, & Marchal, 2008). Dowden and Sayre (2010) went as far as saying that "*the foreseeable significance of this emerging hybrid, personalized, mobile, location-aware device on museum practice cannot be overstated. The hybrid mobile device will defy physical and institutional boundaries, redefine authoritarian sources and practices and forge new communities with or without the museum community's support. Just as the World Wide Web has redefined the public role of museums, hybrid mobile devices promise to improve by allowing museums to focus on content and strategy rather than hardware, while taking full advantage of the tools and technologies of a multi-networked world.*" (p.35).

These transformative devices were endorsed by museums as complaints regarding traditional museum audio tours increased. These tours with standardized content are now considered so generalist and homogeneous, and frequently over-simplified to appeal to a broad audience that they loose the interest of both novices and experts. They are also reproached for dictating visitors' movements and time spent in the galleries, and for generating crowding around exhibits as visitors look primarily at the objects featured on the audio tour. In addition, audio and multimedia tours compete with human docent tours and are criticized for replacing a social interaction with an isolating technology (Proctor, 2011).

Where current smartphones and tablets have set themselves apart from these reviews is in their capacity for personalization, customization and individualization, three key modern trends (Stogner, 2009) that override the uniform experience facilitated by traditional audio tours. They can respond to visitors' desire for participation, social tagging, networking and crowdsourcing. They also connect what visitors find online before going to the museum with the onsite experience, and they extend the visit beyond the building (Jarrier & Bourgeon-Renault, 2012). Moreover smartphones and tablets give the museum an opportunity to be included into the everyday environment of individuals (Arvanitis, 2005), and encourage a direct dialogue between visitors and the museum, and a dialogue between individuals and their peers about the museum experiences (Stein, 2012).

Nevertheless, adoption of modern mobile technology in museums has not been without concerns. Personalization, one of its most auspicious features for some, is considered problematic for others for giving visitors the opportunity to concentrate exclusively on their own particular needs and interests, and narrowing their exposure to new sources of information and limiting the role of serendipitous discovery (Marty, 2007b). A possible attention divide between the digital content and the museum exhibitions has also been pointed to as a negative factor (Hsi, 2003; Woodruff, Aoki, Hurst, & Szymanski, 2001), exacerbating a heads-down experience that is locked to devices that easily distract and disconnect visitors from the surroundings, including social interactions with family and friends. For example, the Cooper Hewitt moved away from an app-enabled mobile device approach when deciding what the digital interactive experiences were going to be since they were looking to support an audience profile with more families and social groups (Chan & Cope, 2015).

Still, it is possible to say the benefits of modern mobile devices in museums have prevailed over their potential problems, when considering the widespread adoption of the technology by institutions across the world (Tallon, 2013).

One particular form of technology, Augmented Reality, as applied to mobile devices used in the museum setting, is reviewed next. Its particular features have taken it into the spotlight and arguably suppressed some of the criticisms pointed at mobile technology.

3. AUGMENTED REALITY IN MUSEUMS

Traditionally, museum exhibition designers move visitors beyond the primary experience of viewing objects, to an interpretive experience using passive and directed secondary devices like graphic panels, explanatory text, videos, or even interactive displays and mobile devices. However, this supplemental material does not interact directly with the objects and the visitor must make the decision to invest further time and effort to read the graphic panel or see the video, make sense around it, and then return to the object to construct meaning.

AR technology, which started to enter the museum landscape in the early 2000s, promised to reimagine this interaction between the visitor and the object. The most commonly accepted definition notes that "*AR allows the user to see the real world, with virtual objects superimposed upon or composited with the real world. Therefore, AR supplements reality, rather than completely replace it. Ideally, it would appear to the user that the virtual and real objects coexisted in the same space.*" (Azuma, 1997, p.356). In brief, AR combines the real and virtual, in an interaction that takes place in real time and where the virtual content is aligned to particular locations or objects.

The application of this technology, especially to mobile devices, merges the experiential and interpretive aspects of perceiving an object in a museum exhibition to generate a singularly integrated, meaningful experience (Elinich, 2011) that is entirely dependent on the real world. Ideally, the visitor no longer has to divide their attention between the surroundings and the supporting analog or digital materials. The two realities coexist on the display, which dodges the claim of disconnection and heads-down experiences as artifacts of mobile devices. For this melding of realities, AR has been regarded a tool for museum innovation (Schavemaker, 2012) and considered a promising technology for enhancing the interaction between visitors, collection objects and their contextualized information (Weng, Parhizkar, Ping, & Lashkari, 2011).

In exploring the concept of the postdigital museum Parry (2013) refers to AR as the epitome of the blending between the physical and the digital that is increasingly likely to characterize the future new media experiences in museums, blurring the traditional distinctions between a digital and a non-digital approach.

The following sections review how the adoption of AR was initially imagined at museums and actually unfolded, from early applications to more developed and stable solutions later.

3.1. PREDICTIONS AND REALITY

The New Media Consortium (2005) highlighted AR for the first time in the 2005 Horizon Report predicting the time-to-adoption as four to five years. The report mentioned some of the projects taking place at the time, most of which in the context of academic research and a few early location-based games. That same year, AR was considered one of the 10 most important emerging technologies for humanity (Mike Adams, 2005). Ten years after that, the estimated annual revenues from AR services and applications were $1.2 billion (Sorrell, 2015); by 2018, 200 million users are expected to have AR apps; and by 2019 the annual app revenues are foreseen as $2.4 billion (Sorrell, 2015). Notably, the interest in AR was extraordinary for such a short amount of time.

Experts predicting the adoption of AR technology were not unaware of museums, and in 2010 – the first year that the New Media Consortium published a companion series to the Horizon Report dedicated to museums (Johnson & Witchey, 2011; Johnson, Witchey, Smith, Levine, & Haywood, 2010) – AR was identified as a technology to adopt in two-to-three years. This report recognized that museums were, in a way, already in the augmented reality business, in the sense they had always been providing multiple ways to connect to each object in a collection; this was particularly true when considering the audio tours enabling the "overlay" of interpretive content (Proctor, 2012b). Therefore, AR technology was to become a continuation of the work done regularly to help visitors better understand and connect with museum exhibitions.

In 2011 and 2012, twice again the Museum Edition of the Horizon Report (Johnson, Adams Becker, & Witchey, 2011; Johnson et al., 2012) placed AR in the mid-term adoption range, recognizing that it had been accepted more swiftly by history and science museums than by art museums, possibly due to a tradition of quiet solace-seeking, devoid of technology, with pieces of artwork. However, the reports reinforced the potential contributions of AR to education and interpretation of exhibitions and collections, as well as for marketing and communications.

The Trendswatch report published by the American Alliance of Museums for the first time in 2012 (Merritt, 2012), equally highlighted AR as a powerful technology capable of letting visitors handle objects in new ways, view rarely seen artifacts or images, and access richer interpretations. After a four-year hiatus, the 2016 Trendswatch report (Merritt, 2016), once again featured AR, coupled with Virtual Reality[2], emphasizing the important role that both technologies can play in formal and informal education, conceivably changing the meaning of immersive learning.

[2] Unlike AR, that aims to enhance the user's perception of and interaction with the real world, Virtual Reality technology completely immerses users in a synthetic environment disconnected from reality.

3.2. EARLY APPLICATIONS

In order to contextualize some of the early applications of AR to museums settings, selected information about the technology – equipment requirements, general production and processing of the augmentation – is included next, to illustrate what initial AR technologists working in museum settings had to overcome.

The main devices used to experience AR are displays that employ video-see-through techniques. Most commonly these are head-mounted displays and handheld displays (Veas & Kruijff, 2010), but alternatively the information on the display is projected directly onto the physical space, also known as Spatially AR (Raskar, Welch, & Fuchs, 2013) or Volumetric AR.

AR systems are divided into five categories – fixed indoor, fixed outdoor, mobile indoor, mobile outdoor, and mobile indoor-outdoor systems (Carmigniani & Furht, 2011). This literature review focuses primarily on mobile systems that, as the name indicates, allow users to move about and experience the augmentation wherever they are. As the later examples will illustrate, early mobile solutions for AR were cumbersome and not handheld, sometimes requiring carrying a computer in a backpack. These initial experiments eventually evolved to compact computers with webcams attached, followed by ultra-mobile PCs (UMPCs) and personal digital assistants (PDAs), cell phones, and more recently to smartphones and tablets.

The process of superimposing virtual content takes place in two stages: recognition of the environment and rendering of the virtual content. The recognition of the environment is traditionally performed either through visual tracking or positioning-based systems – in the first method the camera in the mobile device captures fiducial markers, images or objects; and in the second method, Global Positioning System (GPS) information is utilized. The data obtained from any of the methods is then used to render and align the virtual content over the real world.

Outdoor AR mostly makes use of GPS information for recognizing the environment. But the GPS signals do not penetrate buildings or differentiate the elevational changes from floor to floor, making it generally inadequate for indoor AR. Hence, indoor museums default to visual tracking, which is practical and inexpensive but depends on consistent sources of light to capture the information and requires a clear line of sight between the camera and the entity being tracked (Carmigniani & Furht, 2011; Craig, 2013).

One of the first applications of AR technology in a museum context was prototyped at the outdoor setting of the historical site of Olympia, in Greece, in 2001. Vlahakis et al. (2001) developed the ARCHEOGUIDE, a system that required visitors to wear a head mounted display on a bicycle-type helmet, connected to a laptop and receiver that they transported on a backpack, or alternatively visitors carried a handheld palmtop which they could interact with using a pressure-sensitive pen. The ancient ruins were virtually reconstructed in 3D at the same time that audio narration described their history. Inside the stadium, visitors witnessed virtual Olympic games with avatar athletes, carefully modeled after accurate historical descriptions. In order to better guarantee the quality of the experience visitors had to take predefined tour paths that avoided tree-covered areas with limited GPS data reception.

At the same time that outdoor mobile AR was taking its first steps in cultural heritage sites, Spatially AR was also being prototyped. Bimber, Fröhlich, Schmalstieg and Encarnação (2001) created the Virtual Showcase, which had the same configuration of a museum display case but allowed the object placed inside to be augmented. Several visitors wearing shutter glasses could surround the case, that was sitting on a projection screen, and see the augmented object.

In 2003, an AR system was prototyped bearing in mind the extensive collections that are not on display for lack of exhibition space. The ARCO project employed techniques based on simplified 3D modelling and rendering interfaces for digitized objects, and augmented them on large displays that allowed multiple visitors to experience at the same time (White, Liarokapis, & Darcy, 2003).

The ARToolKit (an open source AR Software Development Kit) was employed by the Human Interface Technology Laboratory for the first time in 2004, at museums and science centers in New Zealand (Woods et al., 2004). All projects involved spatial, temporal and contextual integration into exhibits and provided visitors with a sense of exploration while aspiring to advance educational objectives. For example, some were based on kiosks with different versions of the MagicBook (a regular book visitors could interact with and augment through a handheld visor) (Billinghurst, Kato, & Poupyrev, 2001). Another project was a composition of fiducial markers that recreated the solar system in 3D.

Between 2005 and 2007 the project Mobile Augmented Reality Quest (MARQ) aimed to develop an electronic tour guide for museums using PDAs as the display, and considering the indoor settings resorted to visual tracking over GPS. It consisted of a prototype app with a game structure for 12-16 years-old dedicated to the permanent exhibition “medien.welten” at the Technisches Museum Wien. The exhibition explored the history of media storage and transmission (Wagner, 2007). Users were tasked to solve puzzles that involved finding particular parts of the exhibition and augmenting them through fiducial markers. The completion of one puzzle unlocked the following steps in the game.

Another application with fiducial markers was done by Kondo et al. (2007) that placed them in front of dinosaur skeletons at the National Museum of Nature and Science in Tokyo, to recreate what the animals’ living appearance would have been. Visitors used handheld PCs with a webcam running software developed with ARToolKit.

Even though fiducial markers provide a robust and fast means for recognition, they also represent the inconvenience and limitation of placing markers in the surrounding environment

– large amounts of markers may be necessary to construct certain experiences, potentially interfering with the exhibition concept, and collection objects are sometimes displayed close together which can obstruct the tracking. This led to the development of image-based and eventually of object-based algorithms that track for certain features, such as shape and color, or for edges, in the camera-captured images.

In 2007 Bruns, Brombach, Zeidler and Bimber (2007) proposed the PhoneGuide, tested at the Stadtmuseum Weimar, that worked without internet connection, using a combination of computer vision and Bluetooth signal coming from emitters placed in the galleries. Once the system recognized an object it displayed the corresponding multimedia information on the mobile phone. The Phone Guide is detached from the formal definition of AR in that the virtual content was not superimposed onto the real world, but prompted the idea of markerless applications to provide a better AR experience within museums.

In 2008, the Musée des Beaux-Arts de Rennes was the setting for prototyping the first mobile AR museum guide that used the actual collection objects (paintings) instead of fiducial markers (Damala et al., 2008). Like the PhoneGuide, the promise was of a less costly and more discrete infrastructure solution in the galleries, but it required visitors to use a belt bag with a multimedia recorder attached to an UMPC with webcam. The video captured by the webcam was displayed in real time on the screen, augmented with the 2D or 3D virtual objects. Further interaction with the virtual content was possible through a menu displayed on the screen.

The markerless approach in a museum exhibition was taken forward by the Louvre-DNP Museum Lab (Tokyo), a project that aspired to create multimedia solutions to facilitate the connection between museum visitors and the art collections (Miyashita et al., 2008). For a temporary exhibition on Islamic art, the Lab developed two AR systems: one composed of a camera combined with an LCD screen connected to a PC station, that was next to the display case holding the object to be augmented; and the other a portable system where an animated avatar assisted visitors with navigating the space of the exhibition.

All of the above projects represent early testing with AR in museum settings and since their implementation until today, temporary exhibitions continue to be fertile ground for experimentation, and the role that AR can play has become increasingly interesting to stakeholders (Torres, 2013). The novelty of the technology still draws attention per se, but museums have become better at integrating AR through creativity and rich content. As predicted, applications are now running more and more in small, compact mobile devices with higher computational power. In fact, today's smartphones and tablets are the most common hardware platforms for experiencing AR. These mobile devices are equipped with cameras, GPS and sensors that enrich the interactive experiences with the information they supply. These devices are also ubiquitous, well-known pieces of equipment to the users, that interact with them in a natural and socially acceptable way.

Moreover, many AR authoring tools have been developed and can be found in the market, which has greatly contributed to the spread of the technology. In particular consumer level development tools, requiring little or no coding experience, let the author focus on the design and content creation. They are cloud-based AR-browsers – the end users download an app, similarly to the process they follow to download native AR apps, but content revisions can take place without requiring app updates and the browsers are platform-independent, reaching a wider audience regardless of their device model or operating system (Mota, Roberto, & Teichrieb, 2015).

Since the early adoption of AR to present, not just the devices and authoring tools have evolved, the focus has changed from implementing the technology to being more aware of the user. However, the motivations and the purposes for employing AR in museum exhibitions have remained fairly unchanged. The following section provides multiple examples of modern AR applications that similarly to the early applications intended to: 1) assist visitors navigating the museum (like the projects at the Louvre-DNP Lab and the Musée des Beaux-Arts de Renne), 2) supplement the existing information on display (like the Virtual Showcase), 3) provide access to what visitors usually cannot experience (like the ARCO project), 4) virtually reconstruct the past (like the ARCHEOGUIDE and Kondo et al. at the National Museum of Nature and Science), 5) provide opportunities for social experiences (like the MARQ project). Additional applications can be identified as well.

It is worth noting that the experimentation and implementation of AR, from early on, was not exclusive to one museum subject, but rather surfaced across museums of art, science, history, and cultural heritage sites. It was also not geographically limited, with museums in different countries, independently or in partnership with research centers, actively deploying the technology. This is still true today as the selected following examples illustrate. Even though the emphasis of this review is on mobile AR, included are some fixed systems, mentioned for their relevancy in representing the breadth of applications.

3.3. APPLICATIONS

Navigation

At some museums, AR technology has led to improvements in delivering information that previously was based on print or audio guides. Arguably, AR has enhanced visitor wayfinding, focusing their attention on particular aspects of the exhibitions, providing more information than what was readily available in the galleries and serving as a translator of that information. Traditionally wayfinding has been and still is a highly relevant area for institutions, in particular the large ones, which actively pursue new ways to steer visitors between different points, with efficiency while meeting their needs (Tarr, 2015). For instance, leading visitors to collection highlights was one of the goals of the Musée du Louvre (Paris) for replacing their conventional print guide with Nintendo 3DS consoles that visitors can rent. The Japanese company Nintendo partnered with the museum and created dedicated software, that includes an interactive map that locates visitors in real time and expands information about the collection, including augmenting some pieces of artwork.

A similar navigation approach was taken by the American Museum of Natural History (New York NY) with the "Explorer" mobile app. Powered by more than 700 Bluetooth emitters spread around the museum, the app can locate and orient visitors carrying their own smartphones with turn-by-turn navigation, superimposing arrows on the galleries and corridors of the museum.

The Science Museum (London) resorted to an avatar of a well-known TV personality and science enthusiast as the host of a mobile tour in the "Making the Modern World" gallery (Davies, 2012). The app is downloadable for visitors' own devices and uses the Vuforia AR browser to recognize nine colored markers that are placed next to some of the highlights of the exhibition; the animated augmented character then expands on the stories and facts about the objects.

Supplementing Reality

AR has also been used in some contexts to elevate what is on display or to supplement the real environment surrounding indoor museums. By providing additional information, either in the form of text, audio or visuals, the technology directs the visitors' attention to particular aspects or phenomenons, possibly otherwise missed.

Some science centers have experimented with AR in an attempt to better meet their educational goals. At the Franklin Institute Science Museum (Philadelphia PA), a few of the interactive kiosks that explore natural phenomena, were augmented to better illustrate the physics explaining the phenomena. For example, the device "Be the Path" demonstrates electrical conductivity and the flow of electricity through circuits when two or more visitors, holding hands, close the gap between two metal spheres. When the circuit is completed this way, a light bulb connected to a battery lights up, and an animation of the flow of electrons is augmented over the visitors' arms (Yoon, Elinich, Wang, Steinmeier, & Van Schooneveld, 2012b). At another kiosk, the classic Bernoulli's principle correlating speed and pressure of a fluid, is demonstrated through an actual floating ball over a tube blowing air. Visitors can interact with the ball and see on a screen the augmented arrows surrounding the ball that indicate the changes in air pressure and speed.

The Exploratorium (San Francisco CA) also developed science inquiry activities, at several locations in the San Francisco Bay Area. The series "Science in the City", made available with the AR browser Layar, introduced stories about places, people and themes related to natural phenomena and the built environment. With their own phones, users could superimpose an altimeter to measure the height of fog at their location, and learn how it moves to nearby areas; or explore zones of geologic interest with active fault lines where the direction of movement was virtually overlaid (Rothfarb, 2011b).

A popular AR based science installation was the "Augmented Reality Sandbox", developed at the University of California in Davis (Reed et al., 2014). A combination of a real sandbox, a Kinect 3D camera and a digital projector suspended above, provides the visualization of earth science concepts – as the sand is physically displaced, an elevation color map, topographic contour lines and simulated water stream flows are augmented over it and change accordingly to depict virtual watersheds. The project, which is available under a General Public License, has been constructed in more than 100 venues in different countries (L. Chang, 2015), including science centers like the Lawrence Hall of Science (Berkeley CA), the Museu Catavento Cultural e Educacional (São Paulo), among others.

Venues different than science museums are utilizing the technology to enhance information they have on display or that is related to their mission. The temporary exhibition "The Life of Art: context, collecting, and display" at the J. Paul Getty Museum (Los Angeles CA), intended to tell in depth stories and foster close and mindful looking at a small number of singular objects. To support that goal, a companion iPad mobile app was developed with AR technology to help users focus on the details of each piece and see them from different perspectives (Checchi, 2013).

Getting more comprehensive views and decoding the inspirational influences of the architectural art of Gaudí at the Casa Batlló (Barcelona) were the objectives for developing a videoguide with AR. The furniture and design elements were animated to evoke the natural and organic shapes Gaudí used in his designs. Also making use of augmented video, the mobile app developed for the temporary exhibition "A Moment in Time" at the Laguna Art Museum (Laguna Beach CA), powered by the Aurasma AR browser, turned the stillness of photographs of people caught in a moment of action and contextualized their movements with the videos from which the photo frames had been extracted.

Reinvigorating Antiquated Exhibitions

One of the realities museums face is the aging and degradation of exhibitions paired with the challenge of undertaking large-scale renovations that are resource intensive (Nesbitt, Maldonado, & Mast, 2014). This is especially true at science museums and aquaria given the complexity and expense of unmounting and moving objects such as whales and dinosaurs. The consequences are exhibitions that fall out of visitors' grace and become regarded antiquated and not keeping up with modern interests and preferences.

AR technology has been adopted by some museums in an attempt to virtually invigorate antiquated settings. For instance, the Banff Park Museum, unchanged since 1903, has a mandate to not modify the building or its taxidermy exhibition in any way, and has contemplated AR as a solution to keep its relevance for contemporary audiences (Mor, 2012; Mor, Levy, & Boyd, 2012).

The Field Museum (Chicago IL) decided to revitalize one of its oldest exhibitions, the Hall of Plants of the World, with a temporary AR gaming app developed by high school students that were part of a summer internship. The students worked directly with scientists and digital learning specialists to conduct research in the botanical collection of the museum and communicate their findings to the general public by augmenting the static and long-standing plant models that populate the exhibition (Grainger Digital Studio, 2016).

The Ayala Museum (Manila) employed AR technology to enhance a long established form of exhibition in museums, the dioramas. The displays, that date from 1974 when the museum opened, depict iconic scenes in Philippine history, from the pre-colonial period to independence. Visitors can rent devices to see the "Diorama Experience of Philippine History" where animations, realistic sound effects and voice narrations augment the exhibition (Ayala Museum, 2015).

This type of application of AR technology in museums, one that reimagines the Visitor Experience in an outdated exhibition, is the focus of the research described in this dissertation, and is further discussed later (p.45).

Accessing the Inaccessible

One of the most renown use cases for AR in a museum context took place at the Stedelijk Museum (Amsterdam). The institution has a dual role to display modern and contemporary works of art in its museum galleries, and at outdoor public spaces, providing tours, symposiums and lectures. The indoor offerings were, however, unavailable during a major renovation that closed the building for several years. This was seen as an opportunity to explore innovative ways of presenting the collection virtually at public events in order to sustain the relationship with the onsite audience (Schavemaker, Wils, Stork, & Pondaag, 2011). The "ARtours" endeavor consisted of projects of different scales, truly experimental in their conception, given the adoption of the AR browser Layar which had only been available for six months and was still needing improvements. In one project, art students were inspired by the collection to create their own work that was augmented in the park outside of the closed building; another project took place at a music festival, where attendants could "borrow" pieces of artwork and virtually hang them anywhere around the venue. Also in the Netherlands, the Architecture Institute created the "Urban Augmented Reality Underground" experience, a native multiplatform mobile app that revealed the subterranean landscapes of Amsterdam, Rotterdam and The Hague, with its archeological findings and subway tunnels.

This idea of affording contextual and in situ access to what cannot be experienced otherwise is a strong feature of AR and very promising for museums. Access to prehistoric caves, restricted to public visitation for conservation reasons, was made possible by the MARCH project (Mobile Augmented Reality for Cultural Heritage) (French Pyrenees) (Choudary, Charvillat, Grigoras, & Gurdjos, 2009). The mobile AR system ran on a Nokia smartphone and recognized simple colored images placed at the corners of photographs of the cave wall engravings. Scientific drawings were superimposed onto the engravings to help visualize and interpret the figures that are faded and can be confusing.

At the American Museum of Natural History, experiencing outer space became possible with the companion AR app to the temporary exhibition "Beyond Planet Earth: the future of space exploration". Eleven simple black and white images were spread around the displays and unlocked 3D animations of spaceships and asteroids to visitors' devices. Those images were also available for download at the exhibition's website, which made the AR experiences accessible outside of the museum. Beyond Planet Earth in 2012 was the first AR app to be acknowledged with a MUSE award, the high standing annual recognition offered by the American Alliance of Museums.

Reconstructing the Past

Using AR technology to reconstruct the past has been a recurrent theme in museum applications, both the deep past and the recent past. For instance, reskinning and bringing dinosaurs back to life is a formula repeated across different museums with natural history collections. In 2003, Sauer and Göebel (2003) conceptualized a method to achieve the Jurassic Park theme at the Senckenberg Museum (Frankfurt) and produced two applications in the following year for the project "DinoHunter" (Sauer et al., 2004). One of them, the "DinoExplorer", equipped visitors with PDAs to participate in a dinosaur hunting game.

The Berlin's Museum für Naturkunde in 2007 implemented the Jurascopes, fixed look-through devices that swiveled like telescopes. Peeking through them, visitors would see the mounted skeletons in the gallery become layered, first with inner organs, then with muscles, afterwards with skin, and finally contextualized in their natural habitat where they roamed, fed and hunted, all accompanied with audio effects. The traveling exhibition "Ultimate Dinosaurs: Giants of Gondwana", which debuted in 2012 at the Royal Ontario Museum (Toronto), in part adopted the idea of the Jurascopes by distributing swiveling iPads mounted on stands throughout the gallery to skin dinosaur skeletons. The exhibition, which became a blockbuster in all museums that hosted it, also made available a mobile app for download, that used colored markers to activate AR in the gallery and on promotional outdoor billboards (Elshafie, 2015).

At the Attenborough Studio in the Natural History Museum (London), AR technology was used to deliver the interactive, award-winning movie experience "Who Do You Think You Really

Are?". Each of the 64 seats of the horseshoe-shaped studio has a custom made tethered handheld computer equipped with rear and front-facing cameras, and a touchscreen interface. The film discusses the theory of evolution to an audience mostly composed of families and school groups, and augments extinct creatures and human ancestors in the center of the studio (Barry, Thomas, Debenham, & Trout, 2012; Debenham, Thomas, & Trout, 2011).

Not only has the prehistoric past been the subject of reconstructions through AR technology in museums, more recent occurrences also deserve attention. For instance, the Fraunhofer Institut für Graphische Datenverarbeitung (Fraunhofer Institute for Computer Graphics, at several locations in Germany), that was involved with the Virtual Showcase project described before as an early AR application, introduced the concept of "cultural heritage layers". Zoellner et al. (2009b) developed two AR systems, one mobile using UMPCs and one fixed with a computer display mounted on a revolving aluminum pillar; both systems were used at historical sites and museums to augment existing 2D artifacts, like paintings and photographs. One of the use cases was in Berlin, during the celebration of the 20 years of the fall of the Wall, where a collection of archival photographs from different periods were used to virtually reconstruct several iterations of the Reichstag building that now houses the German Parliament. Another use case utilized satellite images to compare the city before and after the War, along with a 3D reconstruction of the Wall.

Using the same concept but a few years later, in 2010, the Museum of London released the "Streetmuseum" AR mobile app for smartphones (Swift, 2013). At various locations in the city users can see what a site looked like in the past through the overlapping to the actual buildings of archival photos and paintings. GPS location information not only assists user navigation on a map, but also locates them at the augmented spots. Building upon the knowledge gained from and the success of Streetmuseum, the Museum of London later developed the "Streetmuseum Londonium" app, which extends the concept by enabling users to explore the Roman London augmented with soundscapes and animated reconstructions of gladiators, against the real backdrop of the city. In Sydney, the Powerhouse Museum adopted a similar concept to augment items from its photo archive onto the streets of city.

Collective Experiences

As mentioned before, one concern raised about mobile technology in museums is the potential disruption of the traditional experiences that are inherently social, such as the complex interactions within visitor groups, or the interactions between visitors and museum docents (Gammon, 2008; Parry, 2008). Research regarding this topic is conflicting, some studies indicating an isolating effect (Hsi, 2003) and interference with conversations (Woodruff et al., 2001), others highlighting how interactive kiosks promote sharing between visitors (Gammon, 1999). Truly accessible mobile AR has expanded the possibilities of collective experiences through multi-user activities in a virtual space. Rather than just co-located, the users assume different social roles that are collaborative and build mutual understanding around common goals (Reitmayr & Schmalstieg, 2001; Xu et al., 2008). Gamification is another model of engagement explored by museums (Beale, 2011; Burton, 2012) and integrating AR into a gaming strategy was a logical step for some institutions. For instance, the Asian Civilizations Museum (Singapore) combined AR with location-based gaming in an app dedicated to the temporary exhibition “Terracotta Warriors: the first emperor and his legacy” (Thian, 2012). For each of the seven objects on display, a dedicated marker (cleverly blended in as a Chinese character) activated instructions, and visitors could interact with the virtual replicas of the objects and see historical animations, while completing tasks to unlock subsequent levels.

The British Museum (London) has employed AR multiple times, most of them in a format that involves collaboration between young students that go to the museum as part of organized school trips (Lenton, 2013; Mannion, 2012). One in particular, the mobile game “A Gift for Athena” intended for 7-11 year-olds, was designed to interact with the Parthenon gallery – players go through a series of challenges that involve finding sculptures, solving puzzles and playing mini-games, each set examining a different part of the Greek temple (Gamar, 2015).

The American Museum of Natural History also adopted AR as one of the technologies in the mobile game “MicroRangers” (Ferreira, 2016; Graeber, 2016). It explores the general theme of biodiversity loss, moving players between galleries to find specimens and dioramas displays to complete mini-games and triggering virtual content. Gamers obtain a medallion or postcard from the MicroRangers cart found around the museum and use them to trigger augmented animated characters that give instructions on how to advance in the game.

Visitor Content Generation

AR content that is user-generated has been an area of rising interest as museums trend towards being perceived as participatory. In user-generated AR, in addition to receiving and manipulating digital content, the user has an active role in producing the virtual information that is superimposed onto the surrounding real world (Wither, DiVerdi, & Höllerer, 2009). In fact, the concept of “Augmented Reality 2.0” has been introduced as a next step in the evolution of the technology. The advancement assumes active user participation in the creation process, the flexibility to generate geo-references, annotations, 2D drawings, or 3D models, in situ, in an unprepared environment (i.e., without preexisting references of any sort), and with no previous experience from the user (Langlotz et al., 2012).

Even though the technology is not yet mature to enable the 2.0 concept, there are AR applications that have been developed to promote content generation. The same group from the National Museum of Nature and Science in Tokyo that developed the handheld PC application to trigger dinosaur content from fiducial markers subsequently created an AR coloring activity to be employed in different Japanese museums. Visitors, mostly young visitors, were asked to look at the dinosaur skeletons, envision what their color and texture would have been, and to recreate it on paper. As the images were painted in, the application virtually mapped them onto a 3D model of a dinosaur that is seen on the upper part of the coloring sheet. The process is simultaneous, so as the colors are laid out on the paper, the virtual dinosaurs begin to emerge (Yamada & Matsubara, 2013). Disney Research has since taken the concept further by mapping the colors and textures to animated characters (Magnenat et al., 2015). Likewise, the American Museum of Natural History has implemented the approach to the historic Hall of Northwest Coast Indians, where visitors are invited to search for particular collection objects on display, color their representations on facsimile sheets, and through the AR app see and manipulate the virtual 3D object mapped with the texture they created (Joseph, 2016).

At one of the Exploratorium's "After Dark" adult evening events, inspired by four surrealist artists, visitors downloaded the Junaio AR browser to track fiducial markers that gave them access to iconic elements from the artists' paintings. They could then virtually place those elements into their surroundings and augment their companions (Rothfarb, 2011a).

The exhibition "WeARinMoMA" was a rogue initiative by a collective of artists, to virtually place their work at the Museum of Modern Art (New York NY), without the museum's involvement. The six floors of the building became a do-it-yourself exhibition space, and the show was available to any smartphone user with the AR browser Layar installed (Veenhof, 2010).

3.4. PRODUCTION MODELS

The previous review of a selection of museum AR applications was structured according to the motivations that led to their development. Whether transporting visitors to the remote past, or providing opportunities for social experiences, a number of museums embraced AR and served as venues where the technology was matured through a variety of use cases that had the needs and interests of visitors in mind. Nevertheless, developing a mobile AR experience involves careful consideration of the different production models available and thorough planning of the resources required.

This section discusses variants within two major production options. These models are not exclusive to AR and they concern any mobile experience in museums.

Museum-Owned Devices or BYOD

To provide visitors with access to AR mobile displays, museums can opt to make devices available for renting or make them available at no cost; they can also rely on the mobile devices that visitors carry with them to the museum, embracing the so called Bring Your Own Device (BYOD) model, or even adopt a hybrid model that combines these options in some degree

(Burnette, Cherry, Proctor, & Samis, 2011). The implications of the decision are vast, both to the institution and to the visitors.

Having devices available for visitors to rent or borrow for free has roots in the traditional audio tours that started in museums in the 1960s (Tallon, 2008). To adopt such a model, institutions have not only to invest in purchasing or renting the hardware, usually custom made, but also successfully market, distribute, store, recharge and maintain the devices, which has obvious financial and operational implications. However, this option guarantees that access to the applications is dependent only on visitors' interest in using the devices, and any technical issues that can arise from downloading apps onto different devices and different versions of the operating system are controlled for by the venue. Available museum-owned devices have proven to contribute to visitors' satisfaction (Laursen, 2013), even when take-up rates are below 10% for most permanent collection tours (Proctor, 2011).

The BYOD model, gained traction with the popularity and near-ubiquity of Apple devices (iPod and iPhone) from 2007 on. Before that, museums refrained from encouraging cell phone use in exhibitions or even prohibited them, battling the idea of technology detracting from the museum experience and preventing photography of the collections to mitigate damage from flash and to deter infringement on intellectual property rights (Sayre, 2015). But as the proliferation of personal devices and the emergence of apps and social media platforms transformed museum practices (Arvanitis, 2005), the BYOD model began to gain widespread adoption, which is reflected in the AR applications reviewed earlier, and summarized on Table 1 (p.31). In fact, only two out of the 21 applications listed are exclusively accessed through museum-owned devices; all the others rely partially or exclusively on visitor-owned devices. For museums, some of the benefits are the reduction in the investment on technology infrastructure and the possibility of extending the time visitors are in contact with museum content, not only during the visit but also before and after the visit, when they have better control over their pace and time (LaBar, Bressler, Asheim, Samis, & Pau, 2006). Museums can also track user behavior both onsite and offsite using mobile analytic tools.

One concerning question suitably raised at the 2012 Trendswatch Report (Merritt, 2012) noted "*will AR experiences that rely on users bringing their own devices to a museum disenfranchise visitors who don't have (or can't afford) smartphones, iPads or other devices?*" (p.22). Merritt's question has been answered by museums that have adopted a BYOD model and conducted surveys both at the institutional level (Beasley & Conway, 2012; Doering, Pekarik, & Block, 2013; Fusion Research + Analytics, 2013) and more globally (Benhamou & Jarvis, 2014; Fusion Research + Analytics, 2012; Tallon, 2013), with the purpose of better understanding audiences and their relationship to mobile technology. Not surprisingly, results show consistent increase in the app-enabled phones that visitors carry with them, which is especially prominent in individuals that are 14 years-old and above (Beasley & Conway, 2012). The surveys also show that the majority of visitors do use these devices in some capacity during their visit (Benhamou & Jarvis, 2014). However, there will always exist a fraction of visitors that do not own, are not carrying, or even do not want to use their devices. A few influencing factors include being in a foreign country, access to free Wi-Fi, limited data plans and battery life.

In addition, the process of transferring the ownership of the device from museum to visitor actually adds several layers of complexity to ensure achieving museum goals for visitor experiences (Burnette et al., 2011). At the Corning Museum of Glass, Sayre (2015) developed eight related significant variables tied to the success and failure of the BYOD model – 1) visitor awareness of the mobile app, 2) access, 3) device and software compatibility, 4) user capability, 5) supporting amenities, 6) user interest, 7) usability and 8) impact. According to the author, awareness is the most critical component of a BYOD model, since it relies on the museum's concerted effort to promote the experience and be convincing about its value. Other components are also significant, for example providing free internet access to download the app, compatibility with user devices, and user capability having to do with visitors' own technical skills to access and be competent directing the experience. Some visitors require supporting amenities such as charging stations, headsets and, as mentioned, free Wi-Fi. Yet creating awareness and providing access and amenities is not enough, museums must also be the catalyst to increase user interest by demonstrating the potential value of using a mobile device. Finally, the user requires a positive experience with product usability, responsiveness and overall design; and content must be engaging. Green (2016) has a similar perspective about mobile experiences that rely on visitors' own devices. He highlights the importance of visitor awareness, perceived value, access, ease of use and support from the museum, and how it can be relevant for the visitor to have an opportunity to share the experience through social media outlets. The steps involved in a BYOD model can, therefore, be almost defeating to get to the point where the visitor commits to having the experience, when compared to entering the museum and having a choice at the ticket counter for accepting an institution-owned device. Museums that are free or have free days and do not require ticketing have additional challenges.

For museums with the capacity to meet these basic requirements, the consideration seems to be around adopting a hybrid model, one with both device distribution and BYOD. From the perspective of the visitor, that is positively the preferred solution since content can be accessed in multiple ways with a better guarantee of the successful delivery and enjoyment of the experience. From the perspective of the institution, it does place a greater demand on resources.

Museum App	Development	Device Ownership and Cost	Location of Experience
Musée du Louvre guide	Native	Museum (rented)	All Museum
AMNH Explorer	Native	BYOD (free)	All Museum
Science Museum “James May tour”	AR-Browser Vuforia	BYOD (paid)	In-Gallery + Offsite
Exploratorium “Science in the City”	AR-Browser Layar	BYOD (free)	Offsite
Getty Museum “Life of Art”	Native	BYOD (free)	In-Gallery
Casa Batló guide	Native	Museum (free)	In-Gallery
Laguna Art Museum “A Moment in Time”	AR-Browser Aurasma	BYOD (free)	In-Gallery
Ayala Museum “Diorama Experience”	Native	Museum (rented) + BYOD (paid)	In-Gallery
Stedelijk Museum (several apps)	AR-Browser Layar	BYOD (free)	Offsite
Urban AR Underground	Native	BYOD (free)	Offsite
AMNH “Beyond Planet Earth”	Native	BYOD (free)	In-Gallery + Offsite
ROM “Ultimate Dinosaurs”	Native	BYOD (free)	In-Gallery + Offsite
“20 Years of the Fall of the Berlin Wall”	Native	BYOD	Offsite
Museum of London “Streetmuseum”	Native	BYOD (free)	Offsite
Powerhouse Museum tour	AR-Browser Layar	BYOD (free)	Offsite
Asian Civilizations Museum “Terracotta Warriors”	Native	BYOD (free)	In-Gallery + Offsite
British Museum “A Gift for Athena”	Native	Museum (free) + BYOD (free)	In-Gallery
AMNH “Microrangers”	Native	BYOD (free)	Several Galleries
AMNH “Dreams of the Haida Child”	Native	Museum (free) + BYOD (free)	In-Gallery + Offsite
Exploratorium “After Dark”	AR-Browser Junaio	BYOD (free)	In-Gallery
“WeARinMoMA”	AR-Browser Layar	BYOD (free)	All Museum

Table 1 – List of museum AR apps reviewed and their classification regarding type of development, ownership of the operating devices, cost, and location of the experience.

In-gallery, Offsite or Bimodal Application

Museums have various incentives for developing apps to meet different goals and solve myriad Visitor Experience challenges, as the earlier listing of applications illustrated. For example, at the Museum of Modern Art Burnette (2012) speaks about the different motivations involved with creating two different (non-AR) apps. The general MoMA app was meant as both an in-museum and offsite experience that included the audio tour content, and to which was added access to all of the online collection and real time information such as the calendar of events and exhibitions. At the museum, visitors could choose between using the traditional audio guide devices or use their own smartphone, and outside of the museum they could peruse the collection and plan a visit. In addition, the museum developed a second mobile app exclusively dedicated to the temporary exhibition "Abstract Expressionist New York" intending to create an exclusive experience with high-resolution images, a multimedia map, videos, social media integration and dedicated textual information. The exhibition app was mainly to be used outside of the museum, either as an extension of the visit or as a primary content resource for those who did not get to see the exhibition. For another mobile app developed by the Museum of London, Swift (2013) asserts, "*our use of smartphone apps over the past two years has enabled us to extend the museum beyond its building, connecting users with the landscape of London and specific locations throughout the city*." (p.64). These examples reflect different strategies for developing and implementing mobile solutions, that are adopted by museums to suit diverse purposes and reach multiple audiences.

The 2013 Mobile in Museums Survey (Tallon, 2013) showed that the leading mobile experience were in-museum apps, such as the general MoMA app. The survey revealed that the majority of institutions tend to promote singular free apps meant primarily to be used museum-wide during in-person visits in a similar fashion to the traditional audio tours, but with the added benefits of providing the information outside of the museum for planning and collection use purposes. This may be a strategy to reach the largest number of visitors and make the best use of the mobile products life cycle, considering the cost and time involved in their development.

Table 1 (p.31) summarizes for all of the app examples presented, the intended location of the experience. Unlike the general trend that the survey recognized, it appears that AR apps have been mostly developed to accompany temporary exhibitions or focus on particular galleries, being exclusively dedicated to their subjects. The unique experiences afforded by AR and the novelty of the technology have made it a better candidate for smaller scale experimentation. AR apps are specialized tools rather than higher level tools. Moreover, the intended location of AR apps experience, from the sample reviewed, is fairly balanced, with slightly more dedicated to indoor use.

It is therefore reasonable to imagine individuals visiting a few museums and overall coming across the offering of multiple apps, meant to be used for various purposes and locations as this already takes place. Then how does it affect visitors' adoption of technology within museums? What is the overload point beyond which they will not download more apps? Particularly if a BYOD model is used and visitors must weigh the costs for device battery life, storage space, compatibility, and other factors mentioned before against the potential experience. It is known that most mobile device users, despite visiting an average of 25 apps per month, spend 60% of the time with a selection of 3 only, most likely a social networking, game or utility app (e.g. Google Maps) (Lella, Lipsman, & Martin, 2015).

Traditional technology acceptance models are based on perceived usefulness and perceived ease of use, two determining factors that contribute to a user adopting a certain digital tool (Davis, 1989). tom Dieck and Jung (2015) expanded the model to consider the acceptance of mobile AR technology in an urban heritage context using the case study of a navigation app that augmented video, audio and text over certain geo-located sites in Dublin. According to their model, 1) information quality, 2) system quality, 3) costs of use, 4) recommendations from other users, 5) innovativeness (e.g. excitement), 6) risk (e.g. privacy) and 7) facilitating conditions (e.g. hardware, battery), influence the perceived ease of use and perceived usefulness of using AR applications in an offsite digital tour situation. Arguably, this model can also be deemed applicable to AR apps that serve similar purposes for a general indoor museum experience. But in comparison, would an app dedicated to use in a temporary exhibition, specific to certain objects on display, have the same perceived usefulness and perceived ease of use? As noted by Allen (2004) "*if an exhibit has a boring or effortful or confusing component, visitors have no way of knowing whether the reward for persisting will be worth the effort; and in an environment full of interesting alternatives, they are very likely to simply leave the exhibit and move on.*" (p.S18).

As the use of mobile technology in museums evolves, more answers will be available to some of these questions. Looking at visitor patterns of app downloads and app content viewing, particularly in different locations, can contribute to understanding the value of the different location models for each institution.

3.5. CONCERNS AND CHALLENGES

Traditionally the adoption of AR technology in museums has been accompanied by certain concerns and institutions that have endorsed the technology have occasionally been faced with challenges of different technical and operational natures that impair the production and deployment.

Detraction from the Museum Experience

One of the concerns with the use of mobile devices and AR in a museum setting has been that visitors will be focused on the devices and disconnect from the real world. As mentioned before, this is not a concern exclusively towards AR technology. It is also not particular to mobile technology, and it has actually been voiced about any kind of technology embedded in the museum environment. Museum professionals are striving to define the space between engagement and distraction, where new media can be leveraged to expand and enhance the Visitor Experience without overwhelming (or underwhelming) the visitors with new digital tools (Mann, Moses, & Fisher, 2013).

The 2012 Trendswatch Report (Merritt, 2012) wondered: "*Does an immersive AR experience on a handheld device detract from the experience of real-world objects or environments? Will AR users become disconnected from their surroundings? Will AR enhance or detract from the social experience of visiting a museum?*" (p.22). Different authors have shown these are real concerns. The study done by C. B. Madsen, Madsen and Morrison (2012), conducted after the release of a location based gaming AR experience for 8-12 years-old, showed the disconnection from the real environment that the use of the technology elevated. Players spent most of the time looking at the screen and barely noticed the museum itself, given that the game did not actively involve the indoor surroundings. They recommended the design of AR experiences that lead users to take notice of the space and perceive it, rather than just geospatially inhabit it.

The same interconnection with the real environment is desirable on outdoor experiences, as was demonstrated by Wither et al. (2010). Their mixed reality narrative took participants on a tour around Westwood CA, and they found that the locations that proved to be more successful, from the point of view of the participants, were those where the narrative was especially meaningful to the place. Their results show how important it is to keep the flow of the story continuous with the real world in every part of the experience. This was also noted in another outdoor gaming study (McCall, Wetzel, Löschner, & Braun, 2010) where players' feelings of presence throughout the game, particularly decreased while navigating between locations.

It is plausible then to expect that AR experiences that are triggered from museum images or objects in the surrounding environment are an inherent advantage to creating location based AR. The dependencies with the real world should, if nothing else, compel the user to trigger AR for an image or object, and desirably also promote the continuity of the overall experience and invite a deeper understanding and reflection of the surrounding elements.

Replacement of the Museum Experience

To a lesser extent than the concern about detracting from the museum experience, AR is occasionally part of a larger discussion that questions the intrinsic value of the museum objects and exhibitions and how that value holds when it is no longer necessary for visitors to physically go to the museum to have an experience with them. Although it is a more recurrent topic when museums consider applications of Virtual Reality technology, AR can also provide experiences away from the brick-and-mortar institutions, and therefore it is relevant to include this broader concern here.

As part of the shift of the museums' priorities and attitudes towards becoming visitor-centered institutions, the traditional focus on the museum collections has been a subject of reflection (Hein, 2007). The argument of museums being the holders of the "real objects" and therefore providing more authentic and exclusive experiences, as opposed to individuals having access to replicas or virtual 3D representations of the same objects, is multifaceted – the interpretation of the "real object" in the museum context is complex, personal and significantly related to how the objects are presented (Latham, 2015). Visitors exploring the collections in a digital context have greater control over the experience, finding new ways to access, understand and respond to them (Hogsden & Poulter, 2012), and can even express more emotions towards the digital representations than towards the real objects (Alelis, Bobrowicz, & Ang, 2015). There are situations where replacing the physical museum experience is particularly desirable, for example for museums that face problems of overcrowding (Ballantyne & Uzzell, 2011) or are closed for a period of time (Schavemaker et al., 2011) and need to find alternate ways to provide access to their offerings.

Most museums have now begun or even finished digitizing their collections (Heerlien, van Leusen, Schnorr, & van Hulsen, 2013; IMLS, 2006). The process has opened up infinite possibilities, from capturing accurate and reliable data that can serve both scholarly studies and exhibition and outreach uses, to revealing objects that were hidden away for lack of space or conservation concerns (Metallo & Rossi, 2011). But it is still unclear all the ways that the 3D digital representations are going to change, replace or be integrated into the current museum experience. One broad study based on data from annual reports of offline and online museums indicated that online visitors are taking the place of physical visitors, at least in some museums (Hume & Mills, 2011), even though further analysis was called for to fully understand the mechanisms. But as mentioned above, the consequences are not necessarily detrimental to museums; and perhaps one day the "digital object" will be as legitimate as the "real object" (Hogsden & Poulter, 2012).

Gimmickry

Matuk (2016) highlights two issues with AR in museums, one being gimmickry[3]. With innovative eye-catching technologies such as AR, it is enticing for museums to endorse them at an immature stage, driven by commercial goals, rather than after a reflection about their real contributions to the Visitor Experience. As mentioned before, in seeking market share,

[3] The other being privacy, not discussed here. Concerns about privacy and data security in AR systems have been raised (Roesner, Kohno, & Molnar, 2014), but in the context of museums not as prevalently.

museums are sometimes likened to amusement parks and other entertainment institutions (Ballantyne & Uzzell, 2011) that heavily employ digital solutions.

It is not unusual to find a spectrum of museum professionals, at one end of which are the traditionalists that resist the democratizing aspects of digital media, and at the other end, the advocates that loathe any reservations towards technology (Mann et al., 2013). It is through compromises and by applications centered around real-world museum concerns that the best AR use cases emerge, those that have the potential to affect positively on the Visitor Experience.

Innovation of audience participation has been considered one of the most pivotal reasons why a museum would embrace AR (Schavemaker, 2012). Its effect can be comparable to that of the adoption of radio broadcast technology in museum guides in 1952, which provided an alternative to docent guided tours, and was arguably one of the most transformative technologies for museums in the 20th century. Information on demand and by choice reflected the trend towards personal relevance and interpretations, interactivity, and easy access and control of content (Tallon, 2008). Above all is the realization that AR technology, like any other technology, does not have an intrinsic value per se, but rather lives off of the content it carries (Schavemaker et al., 2011). To avoid what back in 1997 was called the "technology trap", meaning the pursuit of technology for its own sake (Šola, 1997), AR needs to be effectively woven into the narrative, integrating the virtual with the physical and ensuring that the interface becomes a transparent layer, so that it truly becomes a storytelling tool (Barry et al., 2012).

Production and Design

- Cost

Museum technology has traditionally been the privilege of large museums (Spinazze, 2010) and similarly, mobile apps are generally associated with larger institutions with higher financial capacity, which often make them available to download for free (Valtysson & Holdgaard, 2011). The same is true when considering AR apps, as seen on Table 1 (p.31), where mostly prominent institutions such as the Museum of London, Powerhouse Museum and the Exploratorium, among several others are listed, and where only three out of 21 apps are not cost-free. This is a good indication of the still fairly high production costs of app development and the production of quality media.

The deployment of AR experiences to the end-user can be categorized as platform-specific or platform-independent. Platform-specific requires the download of a native app from a distribution platform like the App Store (for Apple devices with the iOS operating system) or Google Play (for devices with the Android operating system). Platform-independent experiences rely on software platforms such as the increasingly popular AR browsers. In this case, the end user also downloads an app, but they are cloud-based (instead of native) (Mota et al., 2015).

Table 1 includes which platform type each of the reviewed apps embraced, revealing a somewhat similar distribution between the two options. Nevertheless, they carry important differences between them.

Native apps are developed for a particular operating system and device screen size (e.g. for iOS and iPhones), meaning that to reach out to users of varying device formats and operating systems in a BYOD model, several versions of an app need to be tailored. Therefore, museums trying to reach different audiences with a native app are responsible for purchasing the selected SDK (or instead use an open source solution) and for hiring software developers. They also have to create the content, in addition to maintaining and updating the multiple versions over time.

Alternative to native apps are AR-browsers, which are device agnostic and are maintained and updated by the companies that provide them. When using these non-programming authoring tools, museums are left to focus on content production only, and any changes to it take effect immediately, rather than having to resubmit to the distribution platforms as the native counterparts do, and if using Apple, waiting for approval (Forbes, 2012). The price tags are markedly different, but so can be the experiences offered.

The majority of AR-browsers specialize in geo-located and/or image based AR experiences, thus being restricted to taking place outdoors or being dependent on printed media, respectively. Currently there are no AR-browsers with object recognition, i.e., in-gallery experiences with 3-dimensional pieces that are augmented and feature 3D-tracking. This technology can only be accomplished through native development. It is also with native apps that museums can customize experiences, introduce exclusive features, and offer apps that include non-AR content such as videos or games. Additionally, AR-browsers are internet reliant whereas native apps, once downloaded, can be self-sufficient.

- Quality of the content

In addition to the costs involved in app development, the quality of the content, which can greatly affect the Visitor Experience, is another challenge in the production of a museum AR tool. Augmenting the reality of static places, images or objects, commonly involves enabling them with sound, animation, 3D imagery, i.e., rich multimedia layers that require good storytelling skills combined with technical expertise and access to specialized media production software and digital scanning hardware. Plenty of digital content is at fault for not providing a sense of scale or texture to the original objects. There have been three-dimensional sculptures displayed bi-dimensionally, photos of paintings and artifacts represented as being the same size, low-resolution scanning has degraded textural and color information, and to some the most devious is how digital content can be altered and manipulated, inadvertently or intentionally in such a way that the interpretation is askew (Stogner, 2009).

Zoellner et al. (2009a) spoke of how cultural heritage AR experiences can suffer from poor quality virtual reconstructions and lack of robust markerless tracking solutions, in addition to doubtful scientific accuracy. These remarks will not be true for all, but inevitably there is a varying degree in the quality of AR experiences, which are dependent not just on the cost but also on the expertise of the production and the motivations to do it.

- Onboarding and duration of the content

The production of AR apps is still lacking robust design guidelines to follow. Going through the process of gathering data in a myriad of contexts and prototyping and performing front end evaluation, presents a great deal of challenges (de Sá & Carriço, 2008) that have impaired the growth of the field. Nonetheless, general design practices for mobile AR applications that have a user-centered perspective have started to emerge (Huang, Alem, & Livingston, 2013; Ko, Chang, & Ji, 2013; Kourouthanassis, Boletsis, & Lekakos, 2015) and give guidance in the context of museum experiences.

Considering the relative novelty that the technology represents in such environments, visitors should not be expected to be familiar with the concept and even less with the technical operating procedures for accessing the AR experiences. One study has shown the importance of introducing from the start the underlying principles of the technology at the risk of visitors not going beyond the introductory stages (C. B. Madsen et al., 2012). For example, the unassuming advice of using clear on-screen instructions on how to operate the device to access the augmented content is necessary (Rolim, Schmalstieg, Kalkofen, & Teichrieb, 2015).

Moreover, it is well known by museum studies that the majority of visitors do not spend long periods of time when at an exhibition (Serrell, 1997), which is only exacerbated by crowdedness and museum fatigue – a classic concept that is under scrutiny, but largely means decreased visitor attention over time (Bitgood, 2009). Hence, content duration is a key variable to consider, and AR experiences in particular that have animations and videos, which require holding the mobile device in place for the extent of the experience and therefore are prone to being strenuous.

- Indoor environments – light, line of sight, internet access and noise

Some inherent features of mobile AR technology – such as its reliance on ambient light for camera recognition of the surrounding environment, the requirement of an unobstructed line of sight for the environment capture, and the often dependence on internet connection, at least to download the app and frequently to stream content – are among the greatest impairments to developing AR experiences in indoor museum contexts.

For instance, Mor et al. (2012) mentioned that the light conditions necessary to activate augmented content could be incompatible with the conservation requirements of the objects on display at the exhibition they were working on. Miyashita et al. (2008) found it necessary when developing a museum guide at the Louvre-DNP Lab, that the system operated in relatively dark environments, given the dimly lit conditions of the galleries it was going to be implemented in. Zoellner et al. (2009a) recognized the same problem for cultural heritage projects, mentioning the necessary robustness of the tracking technology to handle large environments with difficult lighting conditions.

Problems with access to the collection objects were observed at the Musée des Beaux-Arts de Rennes, by Damala et al. (2008). They noticed how the behaviors of many school groups deprived visitors of choosing their own itinerary and interfered with the physical space allotment and quality of line of sight to the objects they were interested in augmenting. This was a similar problem to what was noted at the Museum of London (Davies, 2012) and is expected in many other museums that face problems of visitor overcrowding.

Internet access is one of the most discussed difficulties of indoor museum environments considering that cellular connections in some institutions may not provide enough bandwidth or stability to support a mobile AR experience. This is worsened with international visitors that often refrain from using personal data plans for incurring expensive roaming fees. The alternative, which is Wi-Fi provided museum-wide or in-gallery by the institution, is not always possible, for reasons ranging from cost to having historically designated buildings which interferes with renovations needed to install connectivity. Thian (2012) experienced this exact problem: "*wireless connection and phone reception is very weak inside the museum building, and especially in the special exhibition gallery. Before the exhibition was launched, several routers were installed to boost the connectivity strength. However, due to the massive stone construction of the building and network infrastructure in the area, only limited bandwidth could be made available. Network congestion occurred when the crowd started to download the app concurrently at the first and fourth marker.*" (p.8). Their download time was up to three minutes (20Mb mobile app) and multiple visitors were observed giving up and moving away to other parts of the museum.

One last challenge for indoor museum AR experiences are the noise levels that some galleries are prone to have. Museum crowdedness is not a new subject and is inevitably linked to large iconic museums that have become coveted tourist attractions (Ballantyne & Uzzell, 2011). Temporary blockbuster exhibitions that draw sizeable amounts of visitors in relatively short periods of time are also known to have the same problem. For indoor AR experiences that often use audio as a standalone media type or layered in video, the inevitable loud gallery soundscapes are at odds with audio content types. Unlike the traditional audio tours that visitors enjoy by holding the devices against their ears, the audio of augmented content tends to be coupled with imagery, leading the user to hold the device in front of the body where sound is more readily lost into the surroundings.

3.6. RESEARCH

As with any other emerging technology experiencing a fairly sudden burst of interest and rapid growth, the existing body of research on AR across all domains is far more focused on enabling the technology than in studying the factors that concern its users (Dünser, Grasset, & Billinghurst, 2008; Swan & Gabbard, 2005; Zhou, Duh, & Billinghurst, 2008). For mobile AR, location detection and/or image recognition algorithms, information retrieval from different data sources and computational efficiency have been the main focuses (de Sá & Churchill, 2013). In fact, only a successful application of the technology – through applications that are user-centered – leads to real opportunities to examine the impact of AR systems on human activities and experiences. Without the human study of AR applications, claims on the appropriateness of the technology cannot be corroborated (Li & Duh, 2013; Livingston, 2013).

Using museum exhibitions and their visitors for researching AR was from the beginnings of the technology a desired and convenient setting from both the research community point of view and the museum professional perspective since museums offer contextually rich indoor and outdoor environments and have audiences at different technological skill levels. Authors recognized that human subject experiments with AR would be informative on the novel and engaging new ways of connecting visitors with the collections they chose to see (Damala et al., 2008; Tillon, Marchal, & Houlier, 2011).

As the examples below illustrate, during the introductory period of AR to museums, when projects were still the result of collaborations with research centers and consisted mostly of prototypes, active studies were conducted on the users. A common focus was looking attentively at technology acceptance and usability, such as tailoring smaller interfaces to facilitate navigation and task completion. Later on, as AR began to be more commonplace in museums and was applied broadly to temporary and permanent exhibitions, only infrequently and only in some subject areas, were rigorous and accessible research studies conducted and published in peer reviewed journals. More commonly, museum professionals lead internal evaluations to assess goal achievement on AR projects, such as learning outcomes, and do not venture into broader impact social studies.

In 2001, when the ARCHEOGUIDE was developed for Olympia (Vlahakis et al., 2001), the accompanying study showed that users found it an interesting visit-enhancing tool that they would like to see used in other archeological sites. Understandably, they preferred the compact palmtop interface over the head mounted display, not just for the reduced size but also because the screen was clearly visible even under direct sunlight, and was more affordable to rent. The research done by the MARQ project for a museum AR tour guide (Wagner, 2007), along with other projects developed at the Graz University of Technology, confirmed that mobile phones, despite their lower computational power when compared to personal computers, were suitable for providing augmented experiences, and even desirable given their lower cost and greater familiarity to the users than head mounted displays.

Damala et al. (2008) realized that AR interfaces successfully assist visitors with switching their focus and attention between the real and virtual space, and vice-versa. They also predicted that museum professionals would begin to tap into visitor-owned mobile AR-enabled devices for providing rich and diverse interpretive materials capable of delivering emotional multimedia experiences, which has indeed happened. Similar conclusions were drawn by Miyashita et al. (2008), when the interviews they conducted with visitors revealed that AR helped them with noticing and appreciating the details of the displayed object and gave them an opportunity to see details that otherwise would not have been visible.

More recent studies, like those mentioned below, were able to recruit larger sample sizes, had an extra focus on the experience of the visit, and arguably better reflect today's visitors, since they were done with present-day technology.

Considering that education has been recognized as one of the areas that can potentially benefit the most from AR technology (Bacca, Baldiris, Fabregat, Graf, Kinshuk, 2014; Radu, 2014; Wu, Lee, Chang, & Liang, 2013), and that many museums identify themselves as institutions with an educational mission, it is not surprising that several of the existing research studies tried to assess whether learning is facilitated by the use of AR technology in informal education settings. The context-awareness and interactive nature of AR are promising factors in such settings where learning is voluntary and self-directed, unlike in the classroom (Dede, 2009; Greenfield, 2009; Johnson et al., 2012). AR was also considered appropriate to enhance learning about subjects that are difficult to convey otherwise (Matuk, 2016).

One of the concerns raised specifically about the use of AR for educational purposes has been cognitive overload (Dunleavy, Dede, & Mitchell, 2009; Klopfer, 2008), considering that additional information is being superimposed in an already information-rich real world. Studies purposely addressed the concern and recommended design principles (Dunleavy, 2013), for example starting the AR experiences in a simplified structure and increase complexity over time (Perry et al., 2008), replacing text with audio (O'Shea, Mitchell, Johnston, & Dede, 2009), using video narrators of the same age as students (Dunleavy, 2013), and scaffolding each experience at every step to achieve the desired learning behavior (Klopfer & Squire, 2008).

In fact, using a combination of knowledge building scaffolds and augmented experiences in a science museum proved to lead to greater cognitive gains (Elinich, Yoon, Wang, Schooneveld, & Anderson, 2013; Yoon et al., 2012b; Yoon & Wang, 2014; Yoon, Elinich, Wang, Steinmeier, & Tucker, 2012a). Across different studies, individuals going to the Franklyn Institute Science Museum as part of school fieldtrips, were the subject of extensive observation, surveys and interviews about their interaction with different augmented kiosks that convey physical science principles. Several conditions were compared: no augmentation; just augmentation and no other scaffolds; and augmentation and light scaffolding, in which labels in the form of directed questions were by the kiosk. The researchers also compared augmentation and scaffolding at different levels, such as in the form of group collaboration to brainstorm possible answers to the questions but answering them individually in the response sheets after the experience; or higher scaffolding like collaborating to answer the questions during the experience. Without any augmentation students did not demonstrate a significant increase in the understanding after the interaction, leading to the conclusion that augmentation made an impact on conceptual knowledge. The increase in the scaffolding allowed for amplified cognitive abilities in terms of theorizing about the scientific phenomenon, but had an inverse relationship with the students' informal behaviors, i.e., by formalizing the museum experience, they responded as they would in a classroom context. The authors established that the unique participation afforded by informal learning environments may not be compatible with scaffolding for deeper level understanding, when the environment stimulates a classroom.

Other studies have concluded on the positive effects of AR towards learning performance in museum exhibitions of different subjects. For instance, the results obtained by Sommerauer and Müller (2014) at a mathematics exhibition showed that visitors did significantly better on knowledge acquisition and retention tests at augmented exhibits than at non-augmented exhibits (that had traditional physical information displays, i.e., boards, posters, leaflets, quizzes, books). Lu, Nguyen, Chuah and Do (2014) had similar results at an art museum where the information about augmented paintings was better retained and transferred (establishing connections between concepts) after 24 hours had elapsed, when compared to paintings accompanied by text only. Interestingly, in this study, paintings that had a combination of AR and text also underperformed when compared to the AR-only condition, leading the authors to conclude that the physical descriptions interfered with the AR visualizations and decreased the visitors' ability to transfer information about the artwork.

In addition to these investigations concerning the educational efficacy correlated with AR in museums, there is a limited body of work available. Almost no structured research has been conducted where the focus is the experience of the visitors mediated by mobile AR technology and outcomes other than learning are considered.

One exception is the work of K.-E. Chang et al. (2014) that in the context of an art museum looked at the influence of an AR guide towards art appreciation. They compared three modes of visitation – non-guided, audio-guided and AR-guided – and conducted pre-visit and post-visit tests. The study included interviews and observations of visitors' behavior through video recordings from head-worn cameras. The advantages to using the mobile AR-guide were determined as visit autonomy, frequent human-computer-context interactions, improved visual effects, gaining of detailed information about the paintings, and convenient access to the content. AR technology proved to be more effective in carrying the exhibition information than the other modes of visitation, as shown by the post-visit tests. Visitors attributed the improvement to the augmented visuals for supporting the text and the audio and facilitating their observations and exploration of the artwork.

Alelis et al. (2015) also looked at three different conditions, but of interaction with cultural heritage artefacts rather than paintings. They compared the Visitor Experience with 1) the artefacts on a tablet AR app (2D images of the artefacts were augmented with 3D models), 2) with experiencing them as 3D models on a laptop (that could be rotated, panned or enlarged), 3) with physically interacting with the objects. By looking at the potential differences elicited by these three modes of interaction they were intently addressing one of the concerns about AR technology in museums, the replacement of interactions with authentic artefacts with an exclusively digital experience. Both digital modes promoted spending more time viewing the artefacts than manipulating them physically, but holding the actual objects was more enjoyable to participants. The study particularly investigated the emotional responses to the artefacts and the results indicated that the AR app elicited the highest degree of emotions.

Tillon et al. (2011) worked in the context of an art exhibition and conducted an empirical study to understand how AR technology changes the way visitors approach the artwork. They identified three schemes of interaction with the augmented content: 1) video centering, in which visitors experienced the exhibition exclusively mediated by the mobile device that acted like a compass and influenced them to see merely what was featured in the guide, 2) in-bursts centering, in which visitors used visual probing of the surroundings to locate the pieces of artwork but explored them uniquely in a technology-mediated way, and 3) photographic centering, in which visitors primarily prospected the exhibition on their own and only occasionally consulted the device to discover relevant information about the pieces they found more compelling. The photographic centering was the least observed scheme among study participants, but was recognized as the most desirable in a museum environment, based on evidence that supports a strong connection of AR experiences with the real world.

In summary, these studies indicated a positive influence of AR in different museum exhibitions by facilitating information acquisition and art appreciation, allowing for stronger emotional connections with cultural heritage artefacts and even promoting different ways of visualizing and finding interesting interpretations of objects. Nevertheless, numerous other museum subjects besides art and cultural heritage are left unstudied and many nuances within the complexity of the Visitor Experience are yet to be understood. The next chapter will introduce the questions that this research addressed, motivated by the limited existing literature and knowledge regarding the Visitor Experience with mobile AR technology in museum exhibition settings.

III. RESEARCH DESIGN

The Research Design Chapter was structured to begin with the framing of the research questions and to introduce and expand on the theoretical frameworks adopted, based on the literature review. Second, it describes the setting of the research, both the museum and the exhibition where the case study took place (p.52). Third, this chapter provides information on the development of the case study AR mobile app, namely its production, design and content (p.60). Lastly, the research methodology is explained, justifying the methods and instruments applied (p.69).

1. RESEARCH QUESTIONS AND FRAMEWORKS

This research was planned to address two main questions utilizing an AR mobile app as a case study. The app was developed for an antiquated museum exhibition determined to be of relatively low interest to museum visitors.

Part of the research included the production of the mobile app, which in itself followed a framework, described here, that structured the content and the user experience. The case study also addresses different aspects identified in the literature review regarding the production of an AR mobile app for a museum exhibition.

1.1. AUGMENTED REALITY AND THE VISITOR EXPERIENCE

Out of the existing body of work on the Visitor Experience, there is a scarcity of studies that have looked at the influence of AR technology on the Visitor Experience, as the literature review emphasized. The broad number of applications that have been developed with different purposes in museums of various and diverse types from around the world contrasts with the amount of applications that were in fact used to conduct in-depth research studies. Commonly, AR applications are tested for usability and are evaluated to validate internal museum goals, but rarely are they a tool in better understanding the visitors and their experiences. The published examples mostly focus on the learning aspects of the AR-mediated visit or otherwise are scattered and looking to meet idiosyncratic goals, such as validating the technology in response to specific concerns.

The purpose of this research study is to make a contribution to the existing literature and knowledge on the use of mobile AR technology to enhance the Visitor Experience within museum settings. The novel experiences and interactions that AR provides are unlike any pre-existing form of connection between individuals and exhibitions, eliciting a thorough appreciation of how that relationship develops. Therefore, the project set out to address the question:

To what extent and in what specific ways does the use of mobile Augmented Reality technology in a museum exhibition modify the Visitor Experience?

From existing UX studies on AR, one framework was singled out – the work of the author Thomas Olsson (Olsson, 2013). His framework was originally developed for evaluating the UX with mobile AR services. It is a holistic approach where the definition of an AR service includes the application itself with its features and functionalities, the information content, and the experience of the user as the result of interacting with the technology tool. This broad perspective approximates the most established frameworks for studying the Visitor Experience in museums, with the benefit of including specific metrics for evaluating the effect of mobile AR applications on the user.

The framework is the result of user research with various quantitative and qualitative methods focused on consumer-level mobile AR services in everyday situations, such as exploring the nearby environment, shopping and comparing products, and getting location and user-generated information (Olsson & Salo, 2011; Olsson, Ihamäki, Lagerstam, Ventä-Olkkonen, & Väänänen-Vainio-Mattila, 2009; Olsson, Kärkkäinen, Lagerstam, & Ventä-Olkkonen, 2012; Olsson, Lagerstam, Kärkkäinen, & Väänänen-Vainio-Mattila, 2013). The consolidation of the research identified 16 categories of experiences that are expected to be present in users' interaction with mobile AR. The 16 categories were further lumped into six classes that represent higher levels of the user experience: 1) instrumental experiences, 2) cognitive and epistemic experiences, 3) emotional experiences, 4) sensory experiences, 5) motivational experiences, and 6) social experiences.

- Instrumental experiences – which include empowerment, efficiency and meaningfulness – are pragmatic experiences related to users' accomplishment, product performance, and appropriateness and relevancy of engaging with the AR system.
- Cognitive and epistemic experiences – which include awareness and intuitiveness – relate to users' curiosity and desire for knowledge that stems out of the system's semantic features.
- Emotional experiences – which include amazement, surprise, playfulness and liveliness – relate to the subjective emotional reactions that originates from using the AR system, such as pleasure, entertainment, wonder.
- Sensory experiences – which include captivation, and tangibility and transparency – relate to the system's ability to create immersion, sensory and physical pleasure around visual, tactile and auditory stimuli.
- Motivational and behavioral experiences – which include inspiration, motivation and creativity – relate to inspiration generated by the AR system in pursuing a certain goal.

- Social experiences – which include collectivity and connectedness, and privacy – relate to and originate from human to human interactions mediated by the AR system, which may have features that support communication and social values.

To operationalize his theorization around mobile AR, Olsson translated each of the 16 categories into measures, formulated as statements to be used as Likert items to create a Likert agreement scale. These statements were intended to be part of questionnaires to evaluate the user's subjective insights into the experience with AR, and according to the author, "*they provide a sound starting point for designing evaluations and further measures that focus on the experiential aspects.*" (Olsson, 2013, p. 223).

This research took the set of 16 statements and reduced them into six, one per each higher level of user experience identified above, and modified the content and phrasing of the six statements to suit the context of the museum exhibition that served as a case study. The rationale behind the compression was to create a compact instrument not overly taxing to the questionnaire respondent, and to avoid possible sources of ambiguity or misapprehensions, as well as to eliminate dependent statements. The author recognizes himself that "*future research steps could result in, for example, a more condensed list of statements without semantically overlapping items. Naturally, the more holistic, but at the same time compact and easy-to-use the set of measures is, the more effectively it can serve in its purpose.*" (p. 229).

In addition to adapting and implementing Olsson's framework, other more traditional ethnographic approaches in museum visitor studies were included in this research to study how the Visitor Experience is modified by the access to AR technology. As the literature review illustrated, multiple factors collectively contribute to the shaping of the experience, namely visitors' expectations, prior experiences, visit motivation and satisfaction, to which were added the analysis of content viewing and content preferences. Thus, a holistic approach was taken to analyze different aspects simultaneously and the methods employed are described later (p.69).

The combination of the adapted framework for evaluating the UX of mobile AR services together with the visitor studies' ethnographic approaches fits this research in the user-centered models group defined by Forlizzi and Battarbee (2004). Overall the intent is to understand the Visitor Experience through visitors' actions and preferences.

In summary, this research set out to adapt a mobile AR framework for a museum exhibition setting and combine it with additional research methodology to understand to what extent and which specific ways the use of mobile AR technology in a museum exhibition modifies the Visitor Experience. It is hypothesized that the Visitor Experience of visitors that have access to an exhibition enhanced with mobile AR is more positive than the Visitor Experience of those that go through the exhibition without access to the augmented technology, which will be expressed by differences in the 1) pattern of visitation, 2) viewing of content and preferences for content, 3) satisfaction with the visit and meeting of expectations, and 4) rating of the user experience.

1.2. DIGITALLY ENHANCED ANTIQUATED EXHIBITIONS

The second focus of this research and one of the applications of AR technology to a museum context identified in the literature review, is the use of AR to reinvigorate antiquated museum spaces that remain physically unchanged for decades.

Aged settings that have become obsolete over time are, not always, but typically, found at natural history museums. Displays of taxidermied and/or skeletonized collections, and old diorama exhibits can appear to be from an age of trophy hunting and curiosities and less relevant to current issues addressed by natural science museums. A departure from the traditional exhibition design methods and concepts took place in the period from 1930 to 1980, when new forms of scientific research demanded higher level connections, considering the rise of new subjects like ecology, paleontology, genetics, ethology, and others (Rader & Cain, 2008). Systematics – the underlying principle of many of the displays using real specimens – began to feel out of place when environmental concerns and scientific advances became relevant topics in the understanding of science by museum audiences, and many exhibitions were subject to modernization efforts.

The shift in museum practices was simultaneous. At the first issue of the Curator Journal from 1958, Schmidt (cited by McLean, 2007)) uncovered the tension that was unfolding at the American Museum of Natural History between the display of objects and presentation of ideas: "*there is a conspicuous modern trend to attempt, by means of thoughtful arrangement and labeling, to set forth abstract concepts and principles rather than to merely show objects, however intrinsically fine these may be." "It seems evident that this shift of emphasis from the particular to the general is a pervasive one, found or to be expected in all museums everywhere. Not all of the efforts in this direction have been successful, for much experiment and much testing of results is still essential.*" (p.27). These were the foundational thoughts to the current consensus among museum professionals that are against information overload and also reject content that is too concisely didactic, without a sense of openness or wonder about it (Proctor, 2012a).

Nevertheless, as the literature review shows, many aged collections have survived to this day and museum professionals are often confronted with decisions of intervention. Entire make-overs like those that took place in the 1960s are sometimes contemplated, but due to historical and structural restrictions, and more commonly due to lack of resources (Nesbitt et al., 2014), they may not be achievable. In fact, a complete remodeling with disruptive results like what the Cleveland Museum of Art and the Cooper Hewitt Museum underwent is rare and often only within the reach of large scale institutions. Also, museums need to be considerate of existing niche audiences to these antiquated exhibitions, which may range from scholars, to students, to those who appreciate the aged aesthetics (Ashby, 2007). Moreover, there are those who argue for the value of these exhibitions and the educational opportunities they provide (Sanders & Hohenstein, 2015; Tunnicliffe, 2010; Tunnicliffe & Laterveer-de Beer, 2002), and even others utilizing such settings to promote community projects, repurposing spaces and giving a new meaning to exhibition curation (Chester, 2011).

Making use of innovative and interactive technologies has been acknowledged as a way of engagement for exhibitions frozen in decades past (Loveland, Buckley, & Quellmalz, 2014) and AR technology in particular has been applied for that purpose, as in the examples mentioned in the literature review (Ayala Museum, 2015; Mor, 2012). By overlaying the virtual content onto historical and traditional spaces, AR seems to be a good compromise, achieving simultaneously the modernization effect, the preservation of the physical environment, and utilizing considerably less resources than a large-scale renovation would. It carries therefore a potentially high value to long-standing institutions and their professionals. However, there is a complete absence of studies about this kind of AR application – not only is there no information regarding the effects on visitors in such antiquated settings when enhanced with the augmented technology, also there are no insights into visitors' actual perceptions regarding the outdated exhibitions. Therefore, this research set out to investigate:

How does the digital enhancement of antiquated museum exhibitions affect the visit and the visitor?

It is hypothesized that decades old exhibitions do not meet visitors' interest, and that those who visit these antiquated exhibitions enhanced with mobile AR are affected positively, expressed 1) in differences in the pattern of visitation before the digital intervention and after, and 2) in the visitor perceptions.

1.3. IPOP

To address the two questions, this research is based on developing an AR mobile app that was to serve as a companion to an antiquated skeleton exhibition in a natural history museum. The structure and content of the app were designed according to a theory of experience preference developed by Pekarik, Schreiber, Hanemann, Richmond and Mogel (2014), called IPOP. According to the authors, the intention of the framework is "*to give curators and other museum personnel new tools with which to design exhibitions that surprise and delight visitors.*" (p.5).

IPOP is a four-dimensional construct that proposes museum visitors' preferences for 1) Ideas – concepts, abstractions, facts, reason; 2) People – human connection, affective experience, stories, social interactions; 3) Objects – things, aesthetics, craftsmanship, ownership, visual language; and 4) Physical – somatic sensations including movement, touch, sound, taste, light and smell. Studies have shown that exhibitions that strongly appeal to all four dimensions are successful with visitors, and the reason is that, despite everyone being drawn to all of these dimensions in varying degrees, in most individuals, one of the four preferences appears to be dominant.

The IPOP framework has been considered a promising heuristic tool for exhibition designers attempting to immerse visitors in meaningful experiences by offering predictive trends upon which to design experiences (Beghetto, 2014). IPOP has been applied by practitioners that claim it stimulated creativity in the exhibition design team, and promoted a superior level of engagement of the visitors (Léger, 2014). Specifically, the authors of the IPOP theory consider some of its implications for museum practice to be a better appreciation for how visitors differ, encouragement of team decision-making, providing a framework for diverse preferences and understanding visitors deeply.

Considering all of the above, IPOP was deemed as a valuable framework to adopt for the design of the mobile app in the case study as being compatible with the desire to have diversified subjects and types of offerings and to appeal to a wide range of visitors. Additionally, the theory and practice of IPOP emerged from the 1990s to the present from structured observations and interviews with visitors to the Smithsonian Institution museums in Washington DC (Doering, 1999b; Pekarik et al., 1999; Pekarik & Mogel, 2010; Pekarik & Schreiber, 2012). As one of the museums included in that early research is the setting of this research, it was suitable and a desirable design framework to adopt IPOP. Moreover, IPOP had never been utilized to inform the production of a mobile app, which created a novel opportunity to test the framework in such context.

IPOP is considered by its authors to be a predictive model, not simply a descriptive one and one focused on visitor experience outcomes. The authors claim that visitors' relative attraction to the four dimensions influences what they pay attention to and what they do in a museum exhibition. The exhibits where they instinctively stop and the duration of the stop should correlate to the dimension they most identify with. If the framework is indeed predictive, the similar information-seeking context of a mobile app should be no different, and the number of pieces of content and duration they are watched for, should reflect the trends of visitors' preferences in accordance to the identified stronger dimensions.

The mobile app that served as a case study in this research had content developed in the different IPOP dimensions. To the four dictated by the framework, a fifth dimension was experimentally added – Animals. This new category is coherent with the setting of a skeleton exhibition in a natural history museum, which some individuals visit because they have a preference for animal stories, a preference that is stronger than their favoring of ideas, people, objects or physical activities. Hence, the case study in this research is intended to test if IPOP is predictive in the context of a mobile app, expressed by 1) differences in content viewing by groups of individuals favoring each dimension and by 2) visitor perceptions. It also meant to test how the framework holds when expanded to five dimensions.

1.4. PRODUCTION MODELS

The AR mobile app in the case study of this research applied a BYOD model and a bimodal in-gallery and offsite model, both production models as examined in the literature review. The BYOD model encourages visitors to download the app onto their own devices. The bimodal in-gallery and offsite model allows visitors to use the app in the museum to facilitate their visit to the exhibition and later return to the app to extend their experience when they are no longer in the museum.

Operational and financial considerations precluded a potential contribution of the case study to the existing literature regarding the adoption of a BYOD model, when compared to a museum-owned devices model. However, the case study was examined regarding the adoption of a bimodal in-gallery and offsite model.

The goal was to contribute to a better understanding of how a museum app with a dual-location capability is perceived and used by the visitors and to validate its implementation by comparing the device and app usage, and content viewing by users of the app in the museum and offsite.

1.5. CONCERNS AND CHALLENGES

The AR mobile app in the case study of this research was additionally examined to address some of the concerns and challenges identified in the literature review. The review mentioned common apprehensions tied to the adoption of the technology – does it detract from the museum experience, does it replace the museum experience, is it just a gimmick – and the different challenges during production and design such as cost, quality and duration of content, AR experiences onboarding, and indoor design considerations such as lighting, line of sight, internet access and noise.

Some of challenges were intentionally not evaluated, namely cost, quality of content and lighting conditions, given that they present themselves during the development stage of the mobile tools and the focus of the research is on the visitors and their experiences. But the case study was used to assess the remaining challenges and the concerns by recognizing whether they presented themselves and to what degree as examined through 1) visitor perceptions, 2) pattern of visitation and 3) content viewing in the mobile app.

2. RESEARCH SETTING

The case study took place at the Smithsonian's National Museum of Natural History in Washington DC, United States, in one of the Museum's permanent exhibitions called the Bone Hall. For a better understanding of the setting and the visitors, next is introduced the Museum as one of the most visited in the world and the profile of its audience. Following the Bone Hall is presented as an historically significant skeleton exhibition unchanged for over 50 years, which presents unique challenges to modern visitors and museum professionals.

2.1 SMITHSONIAN'S NATIONAL MUSEUM OF NATURAL HISTORY

The Smithsonian's National Museum of Natural History, hereinafter referred to as NMNH or as the Museum, is located on the National Mall in Washington DC, a central area in the city with a high concentration of museums and monuments. NMNH, similarly to many of the other museums it is surrounded by, is open to the public for free, nearly every day of the year. In recent years it competes with the Smithsonian's National Air and Space Museum for second place in the ranking of the most visited museums in the world, which results from the popularity and high reputation of its exhibitions and collections, the convenience of its location, and because it is cost-free. In the calendar year of 2015, NMNH received 6,876,930 visits[4], a number that, similarly to other years, was unequally distributed throughout the months with spring and summer being the peak of visitation (Figure 1).

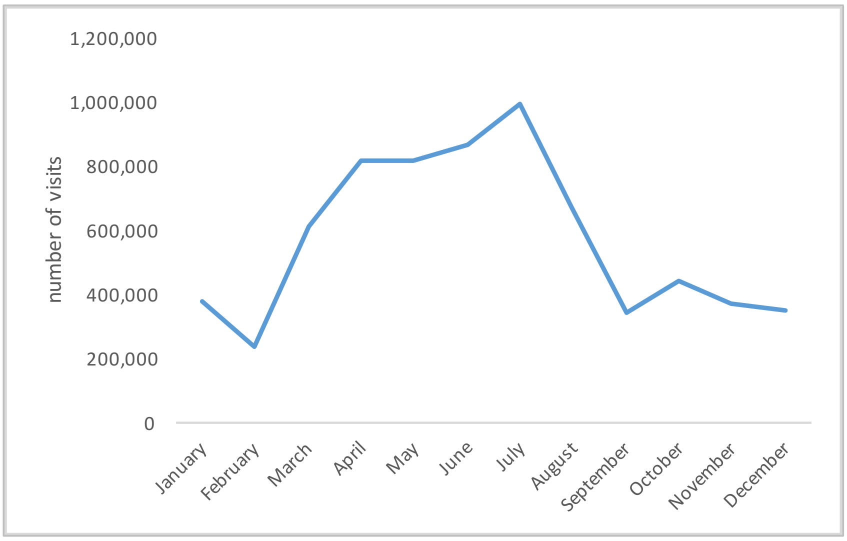

Figure 1 – Distribution of visits to NMNH during the 2015 calendar year. Data Source: NMNH Visitor Count Management System.

[4] This number refers to the amount of visits per year and not visitors per year, due to the method of counting in the Museum – security officers at both entrances are equipped with a manual click counter and register each individual exit, rather than each individual visitor.

The Smithsonian's Office of Policy and Analysis has been conducting survey studies about NMNH's visitors for decades. Some of the most recent surveys in 2010 and 2013 use a 1995 study and a 2004 Smithsonian-wide study to compare results and track trends (Bielick, Pekarik, & Doering, 1995; Bitar, Pekarik, & Renteria, 2013; Doering & Pekarik, 2010; Marino et al., 2004). These surveys trace an accurate profile of the Museum's audience as not significantly changed over time:

- Overall the vast majority of visitors are U.S. residents, of which a small percentage is from the Washington DC metropolitan area and an approximately equivalent amount is visiting from outside of the country. In the winter it is more likely for U.S. visitors to be from the greater Washington DC region than in the summer, and local visitors are also more prevalent on the weekends when compared to weekdays.
- All year round the majority are first-time visitors; however, the repeat visitors are more probable in the winter than in the summer.
- Approximately half of the visits are from multi-generational groups, which are even more prominent in the summer, with winter attracting more adult-only groups and adults by themselves.
- Men and women seem to be equally present, with an average age of 37 years-old, even though summer visitors tend to be slightly younger.
- The great majority of visitors identify themselves as Caucasian, with Latinos or Hispanic, Black or African Americans, and Asian Americans as the largest minority groups.
- The education level is very high, with most visitors reporting graduate/professional degrees or bachelor's degrees.

2.2 BONE HALL

The Bone Hall is an exhibition on the second floor of NMNH. In five connecting rooms with walls lined with glass display cases there are 379 full skeletons and skeletal parts representing all living groups of vertebrates (Figure 2, p.54). The five rooms sequentially hold 1) mammal skeletons, 2) several skeletal parts to describe functional anatomy concepts, 3) bird skeletons, 4) reptile and amphibian skeletons, and 5) fish skeletons. The Hall is approximately 170 ft. (82 m) long and is shaped as a corridor with two entry/exit points that connect to other parts of the Museum (Figure 3, p.55).

On display in the Bone Hall are mounted specimens mostly in still poses arranged in side view without representing any particular behavior or showing the impression of motion. The criteria for their grouping in display cases is taxonomic, which is reflected in the case titles – e.g. Cloven-Hoofed Mammals, Snakes of the Family Boidae, Perciform Fishes. Exceptions are found in the bird room where species are grouped according to their ecological features – e.g. Underwater Swimmers, Land Birds, Running Birds. The glass cases vary significantly in size and they contain anywhere from one skeleton to 26 skeletons. Also, inside them there are identification labels that typically include the common and scientific name of the animals, but most panels are for the entire taxonomic group.

Figure 2 – General view of the Bone Hall. Photo Credit: 2008-10806 Osteology Hall by Chip Clark, NMNH, Smithsonian Institution.

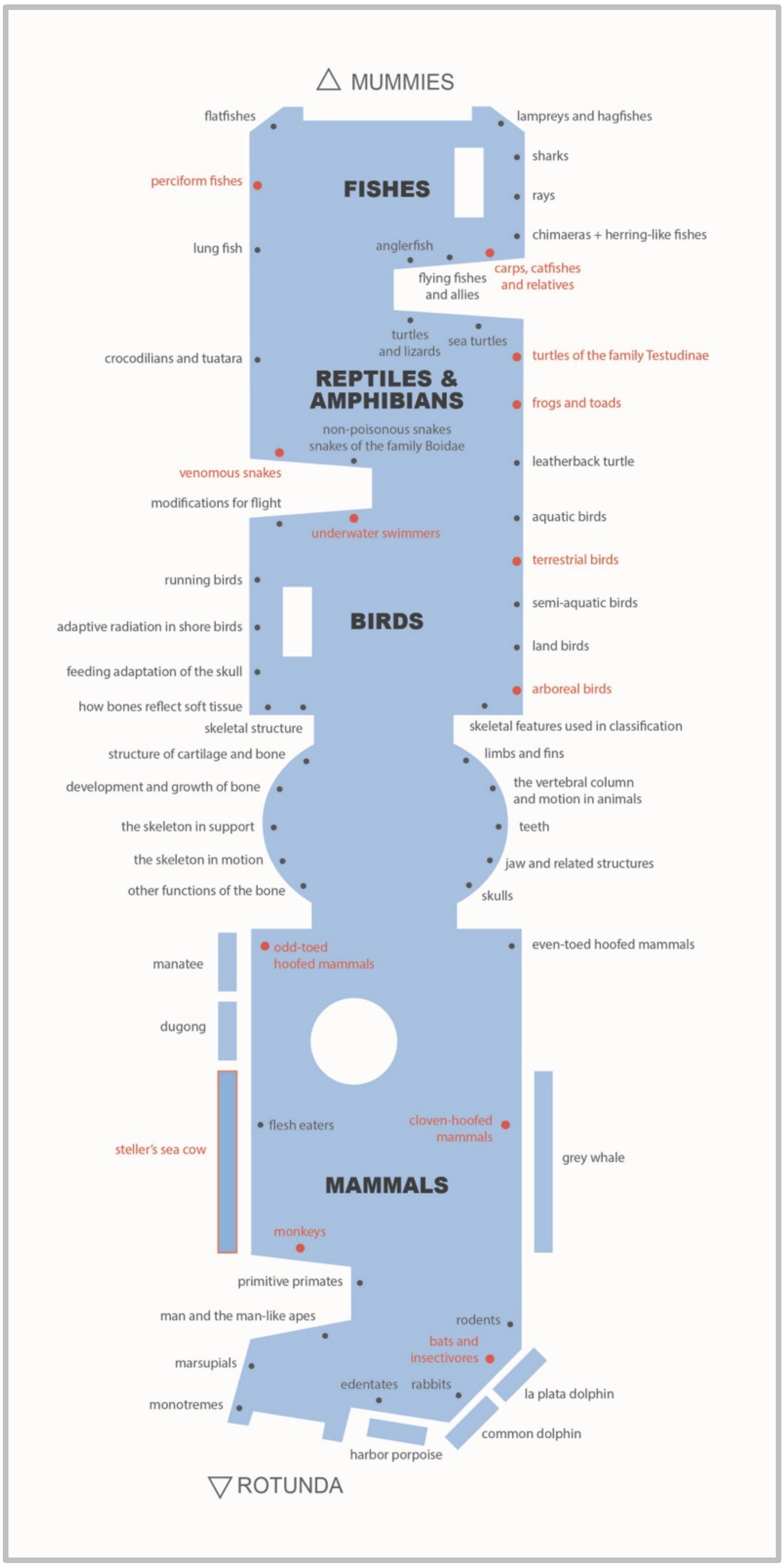

Figure 3 – Floor plan of the Bone Hall. Display cases with Skin & Bones content highlighted in red.

History

The display of many of the specimens in the Bone Hall predates the NMNH building. They were first on view at the Paleontology and Comparative Anatomy exhibition at the United States National Museum, which opened in 1881 with skeletons of extinct and extant species (Gilmore, 1941), hanging from the ceiling or enclosed in free-standing glass cases (Figure 4), in the style of other grand European anatomy exhibitions of the period.

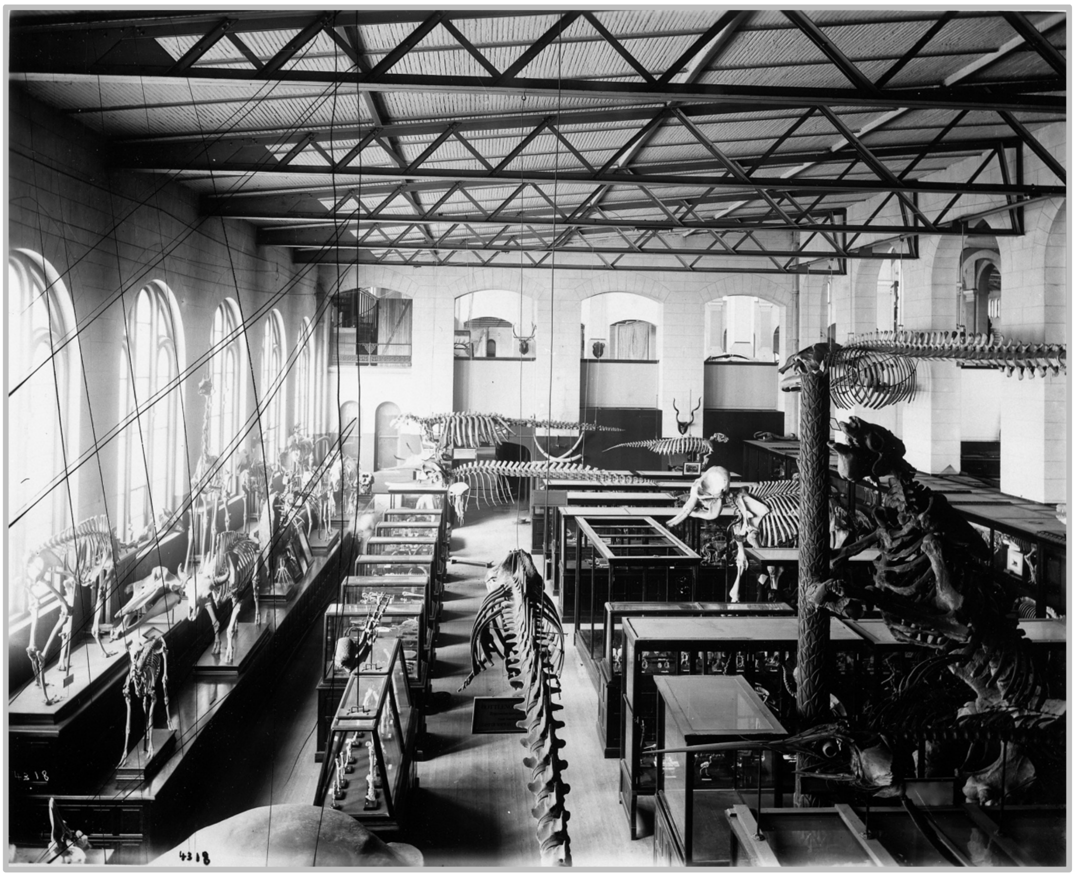

Figure 4 – Paleontology and Comparative Anatomy exhibition at the U.S. National Museum where some of the same specimens that are currently on view at the Bone Hall were included. 1800s. Photo credit: Smithsonian Institution Archives.

When the new U.S. National Museum, now known as the National Museum of Natural History, was completed in 1911 (Kohlstedt & Brinkman, 2004) the specimens were transferred and reorganized. In the 1960s, as part of a major exhibition redesign program in the Museum (Yochelson, 1985), the extant specimens were combined with specimens sourced from the National Zoo and from private collectors to create the Bone Hall (Figure 5). This osteology exhibition is unchanged since then and includes skeletons that are thus the oldest on display at the Smithsonian.


(a)


(b)

Figure 5 – (a) Mounting of the Gray Whale skeleton in the Bone Hall. 1964. Photo credit: Smithsonian Institution Archives. (b) Current view of the same specimen. Photo Credit: 2008-10812 Osteology Hall by Chip Clark, NMNH, Smithsonian Institution.

Exhibition Design

The redesign of the osteology exhibition in the 1960s was curator-driven by individual scientists or small teams specializing on the five vertebrate classes. They were responsible for most of the process, from selecting the specimens to writing the text in the cases' panels. When asked about his involvement with the making of the Bone Hall, Dr. Victor Springer, Senior Scientist Emeritus at the Fish Division of the Vertebrate Zoology Department shared "*Each of the six fish curators was assigned one or more of the individual cases for which he prepared the scripts and oversaw the content.*" (personal communication, September 27, 2012). Another curator, Dr. Richard Zusi, who worked at the Bird Division of the Vertebrate Zoology Department between 1963 and 1994, said "*I wanted to emphasize mainly the osteological differences related to locomotion and feeding, and to show adaptive radiation within birds.*" (personal communication, September 27, 2012). Thus overall the exhibition was planned to convey organization and classification of organisms through direct correlation of unique skeletal structures.

The look and feel of the Bone Hall is emblazoned by the interior design style that marked the 1960s. With the exception of three benches in the mammal, bird and fish rooms there are no other pieces of furniture and the space is open. The text panels often occupy a central position in the cases, displacing the skeletons to the sides. The texts that supplement the identification labels and validate the specimen groupings in the cases, are long and scholarly, with a profusion of specialized anatomical terminology. For example, the label accompanying the Goatsucker bird skeleton (*Chordeiles minor*) reads "*the Order Caprimulgiformes includes the goatsuckers and their allies. These night birds have weak feet and very large mouths, although the bills of most are small. Many catch insects while flying. They are either schizognathous or desmognathous and most have basipterygoid processes*."

The problems highlighted – out-of-date design and impenetrable and irrelevant information for today's non-specialist audiences – in addition to an asbestos abatement concern would call for the shutdown of the Bone Hall and redesign of the entire exhibition. However, given its historical and biological importance there is an institutional reluctance to physically modernize it and the time and resources required to do so are challenging to secure.

Visitor Experience

The majority of visitors to the Bone Hall walk through the exhibition making none or very few, brief stops. Those who stop, do not appear to read the text panels. The underpinning design, meant to convey anatomical and evolutionary ideas, seems to be lost to visitors that use the benches to rest or use the Hall as a passageway to get to other exhibitions.

The above is consistent with a 2010 Museum-wide report (Doering & Pekarik, 2010). In that study, entry questionnaires asked visitors to mark which in a list of 10 experiences they were most looking forward to have. Exiting visitors were asked to indicate which ones they had found especially satisfying. The results showed two experiences with significant increases between the percentage of visitors who anticipated them and the percentage who reported them satisfying: "being moved by beauty" and "feeling awe and wonder". None of the other eight experiences showed significant differences between entry and exit, including the ones that visitors placed first upon entering such as "seeing rare, valuable or uncommon things", "gaining information" or "enriching my understanding". In other words, visitors walked into the museum with greater expectations of an educational experience, but had mostly an aesthetic one. Even though these are generalized results coming from a Museum-wide study, informal observation in the Bone Hall suggests that it is taking place there. This research conducted a baseline study described later (p.70) to assess in detail how the Bone Hall visitors are using the exhibition.

Even if visitors do not to seem to dwell in the Bone Hall, as they would in other exhibitions at NMNH, the space tends to be extremely crowded in peak visitation times during the year – holidays and special celebrations and during summer months (as seen on Figure 1, p.52). The linear shape of the Hall with long and narrow rooms, and with funneling points between rooms, leads to the accumulation of visitors as they stop to look at the display cases. Large groups and families with strollers contribute greatly to slowing or stopping the flow of traffic, and pose significant challenges to visitors with reduced mobility. The amount of people coupled with the hard surfaces and outdated construction of the Bone Hall, lead to ambient sound levels considerably above 80-90 decibels, making communication difficult.

3. MOBILE APP SKIN & BONES

In 2012 NMNH began a digital intervention aimed at repairing the visitor experience in the Bone Hall. One important limitation was to do this without any physical changes to the exhibition. A companion mobile app was developed to the Bone Hall, called Skin & Bones, and it includes AR technology as one of its features. It functions in a BYOD model. Visitors to the Hall can utilize the free Wi-Fi network provided by the Museum (only at that exhibition) to download the app to their devices.

There were affective goals established for Skin & Bones, and no specific educational goals. The app was to resuscitate the Bone Hall, increasing the enjoyment and memorableness of the visitor experience to the exhibition, and improve the communication of the main organizing principles of the Hall. Importantly, it would become an option to visitors interested in delving beyond what is available in the physical space, but not replace it, preserving the possibility of exploring the antiquated and historical skeletal collection just as it is. Even though the primary model of the app was to serve as a companion to the Bone Hall, it was also meant to be a content-rich tool offering engagement opportunities outside the exhibition.

Three aspects have been identified as important to consider when designing for mobile experiences that include AR – the usage scenario, the input modalities and the display device (Ganapathy, 2013). In Skin & Bones, the museum scenario, and in particular a high caliber national museum and the profile of its audience, influenced many of the design decisions that are described briefly in the following sections. The user input was decided to be exclusively tangible under different configurations (tapping, swiping, shaking, pinching) since other modalities would have meant a more complex process of software development or not be appropriate for the context (for example, voice input was never considered given the expected interference with the high volume levels in the exhibition). And the display device was self identified when a BYOD model was selected to implement the app in the Museum. This led to a design process that kept in mind the difference in screen size between iPhones and iPads, and constrained the app to landscape view, which was considered more suitable to the visual content. Other aspects examined in the literature review, in particular the onboarding and duration of the experience, noise levels in the exhibition and internet connection, were recurrently discussed and influenced the production of Skin & Bones.

Thirteen animals were selected to be featured in the app based on the ecological and anatomical stories that could be told. From the 13 animals, 10 AR experiences, 32 videos and four activities were produced. Next is a walkthrough of different aspects of the production process.

3.1. PRODUCTION

The production of Skin & Bones lasted a total of 25 months and the app was deployed to the App Store on January 13th, 2015. It is available to download, at no cost, at: *https://itunes.apple.com/us/app/skin-bones/id929733243?mt=8*.

Skin & Bones was produced by Robert Costello and Diana Marques who were also the designers of the user experience and responsible for writing the scripts (Robert Costello), and for the design of the interface, scanning/modeling of the 3D graphic content for the AR experiences, and design of the promotional materials (Diana Marques). The production team additionally included one software developer, one audio producer and four voice actors, two video producers, one 3D modeler and one 3D animator. A large number of vertebrate zoology specialists served as consultants for the development and review of the content, and some of them contributed assets and are featured in the app.

3.2. APP DESIGN

Technology

Skin & Bones is a native app that runs on iOS 7.1 or later and is compatible with iPhone, iPad, and iPod touch. The Metaio Software Development Kit, commercialized by the German company Metaio specialized in AR solutions, was used to program the deployment of 3D assets. Both static 3D models and animations were included in the Skin & Bones AR experiences. The SDK was capable of object-recognition, with the skeletons in the Bone Hall being the trigger for activating the augmented content that was superimposed and aligned with the animals. 3D tracking is a key feature of the software, meaning the repositioning of the mobile device to face different parts of the skeleton matches the corresponding orientation of the augmented content.

User Experience and User Interface

Skin & Bones was designed to be a simple-to-use mobile app with an intuitively visual and self-explanatory interface. Intended for a Museum with very high visitation that hosts a great range of individuals with varied levels of interest and comfort with mobile technology, it was critical that the app was straightforward, placing content viewing and interaction with the exhibition as its primary target. The app would additionally provide an immediate perception of the layout of the Bone Hall, assisting visitors with planning their excursion in accordance with their content preferences. The user interface, in particular content categories and their layouts, and the navigation within the app were tested with formative evaluations with visitors in the Bone Hall.

Maintaining visual consistency with the exhibition, through the use of color and typography, was the driving force behind the design choices for the user interface. The use of photographs of the skeletons was important to assist users with recognizing in the physical space the animals that are featured in the app (Figure 6).

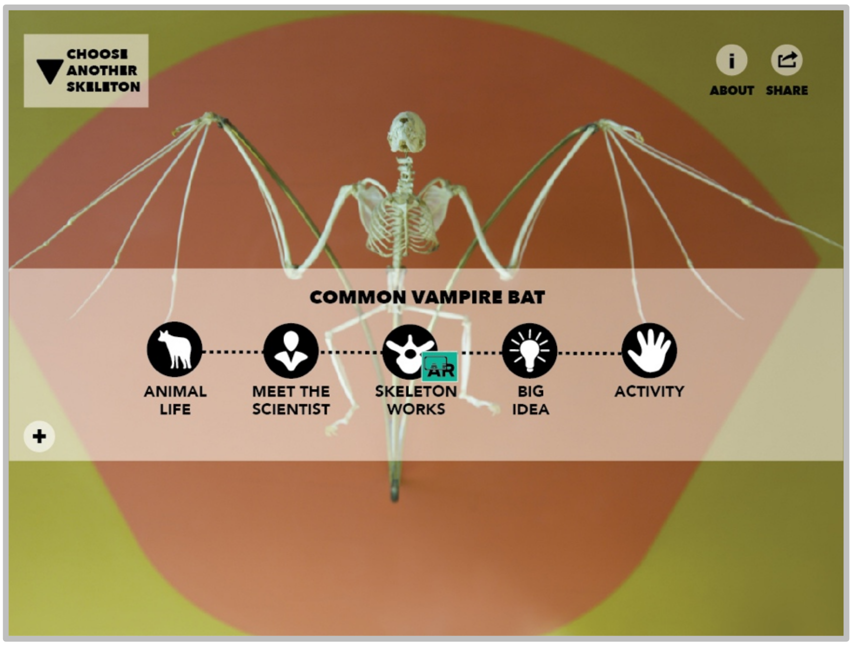

Figure 6 - Skin & Bones iPad screen capture of the main page for the Common Vampire Bat.

Navigation through the exhibition is supported by a map that introduces the 13 animals and their distribution in the Hall (Figure 7). The overall number of buttons and icons was reduced to the minimum possible, and their appearance made conspicuous to ensure good touchability. Redundancy was applied to the way the user moves between screens, which is done either by touching the buttons or by swiping the screen.

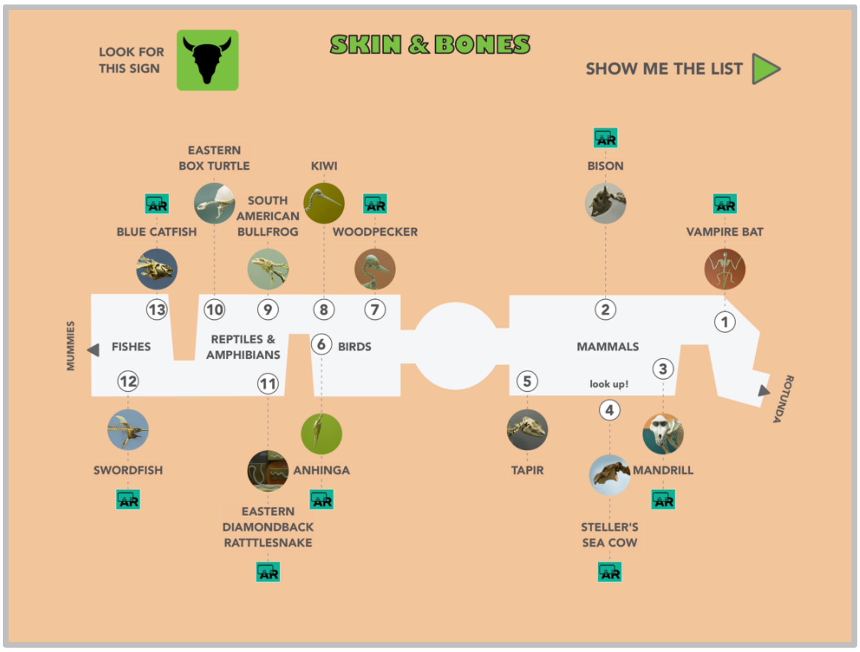

Figure 7 - Skin & Bones iPad screen capture of the map that indicates the location of the 13 animals featured. Each animal has a unique number that matches the number on the glass display case where the specimen is. The map includes the AR logo next to each animal that has augmented content.

The user is given full control over multimedia content: videos do not auto-start, closed captioning is an option and so is expanding to full screen view. Two messages are delivered via pop-up windows: the first if there is no internet connection detected (Wi-Fi or mobile internet, given that the video content in the app is internet-reliant), the second suggesting the use of earbuds or headphones for an improved audio experience.

All of the content pieces in Skin & Bones with a finite duration – videos and animated AR experiences – were designed to be short, up to 0:02:42 for the videos, even less with the AR experiences.

Skin & Bones users were not expected to be familiar with AR technology. A short opening animation alluding to the experiences the app contains was created (Figure 8). It was meant to set the user expectations and introduce an icon through a visual association with an AR experience, which is repeated throughout the app screens whenever augmented content is available.

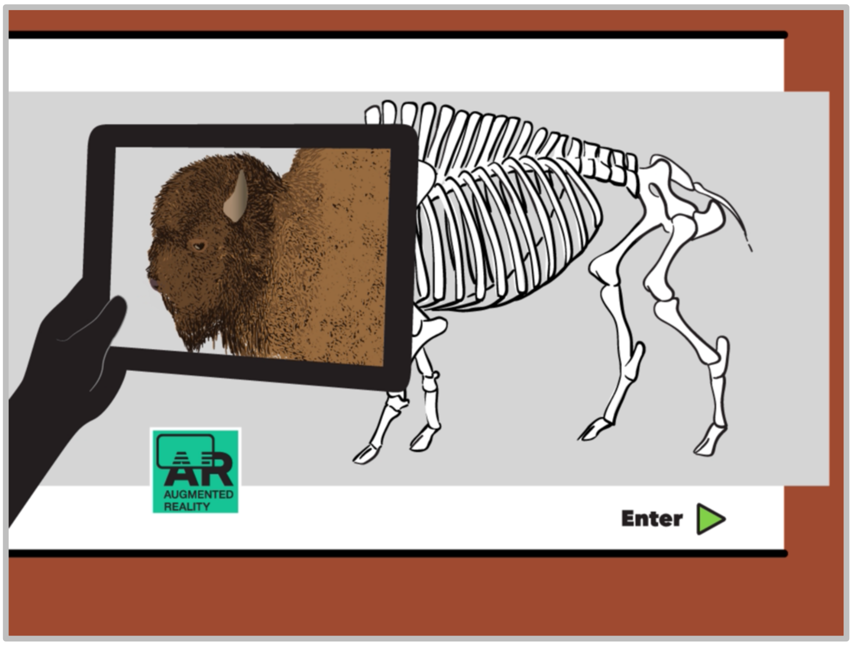

Figure 8 - Skin & Bones iPad screen capture of a frame of the opening animation.

When the user selects a menu option with augmented content, the back camera of the mobile device turns on and an image panel slides up, instructing the user to "*point your device to frame the [animal]*" and the message is illustrated with an image of the device framing the animal (Figure 9, p.64).

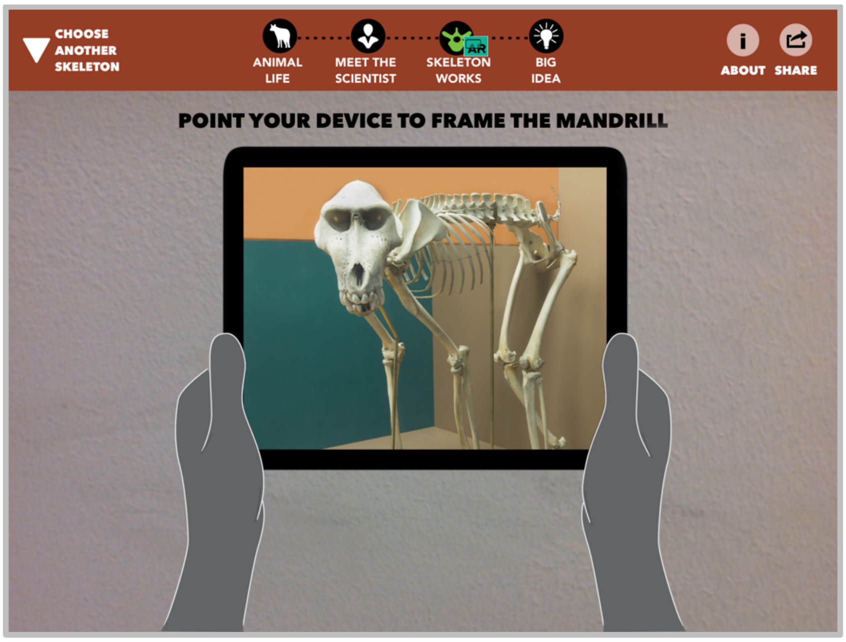

Figure 9 - Skin & Bones iPad screen capture of the instructions to activate the AR content for the Mandrill.

Content Dimensions and Structure

In order to create a balanced visit experience around the 13 animals featured in the app, at least one representative from each major vertebrate group was included and the selection criterion was based on identifying stories of potential interest that filled as many IPOP dimensions as possible. For each animal a menu option offers content in the framework's four dimensions – Ideas, People, Objects and Physical – plus the fifth dimension Animals. However, not all dimension options are available for all 13 animals, which is illustrated in Table 2. The five categories in the menu are (Figure 6, p.62):

- Animal Life – includes videos about the roles the animals play in the environment. They can be referred to as following a traditional format of animal documentary video, highlighting the species in their habitats, their relationships with other organisms, feeding habits, etc. This is the menu option that does not have a counterpart in the IPOP framework.
- Meet the Scientist – Smithsonian scientists are introduced from a human-interest angle by exposing their personal and formative experiences. Their research expertise about the animals was kept at bay, focusing on individual reflections about their upbringings, and interesting life and career occurrences and decisions (Figure 10, p.66). Ten living scientists were interviewed in the Bone Hall, and videos about three deceased scientists were also produced. This menu option is the People dimension in the IPOP framework.
- Skeleton Works – through AR, 3D models and 3D animations are superimposed over the skeletons in the exhibition to communicate particularities of the functional anatomy (Figure 11, p.66) or to skin the bones with the corresponding fleshed exterior, linking the internal

and external appearance (Figure 12, p.66). This menu option corresponds to the Object dimension in the IPOP framework.

- Big Idea – includes videos that explore higher level scientific concepts that make connections across different species or discuss common ecological solutions – e.g., venom as a defense mechanism or echolocation in mammals (Figure 13, p.67). For two animals, American Bison and Swordfish, the Big Idea menu option is composed of one introductory video followed by an AR experience. This menu option corresponds to the Idea dimension in the IPOP framework.
- Activity – uses haptic interactions with the mobile device to enable physical experiences, hence representing the Physical dimension in the IPOP framework. These consist of simple games that involve listening to the animals and making identifications, matching elements by dragging them on screen or reproducing animals sounds through tapping or shaking the mobile device (Figure 14, p.67).

	Animal Life	Meet the Scientist	Skeleton Works	Big Idea	Activity
Common Vampire Bat	✓	✓	✓	✓	✓
American Bison	✓	✓		✓	
Mandrill	✓	✓	✓	✓	
Steller's Sea Cow	✓	✓	✓		
Baird's Tapir	✓	✓		✓	
Anhinga	✓	✓	✓		
Pileated Woodpecker	✓	✓	✓	✓	✓
Brown Kiwi	✓	✓		✓	
South American Bullfrog	✓	✓			
Eastern Box Turtle	✓	✓			
Eastern Diamondback Rattlesnake	✓	✓	✓	✓	✓
Swordfish	✓	✓	✓	✓	✓
Blue Catfish	✓	✓	✓		

Table 2 - Distribution of content in the five menu options for each animal featured in Skin & Bones. Augmented content highlighted in red.

Figure 10 - Skin & Bones iPad screen capture of the Meet the Scientist menu option for the Brown Kiwi.

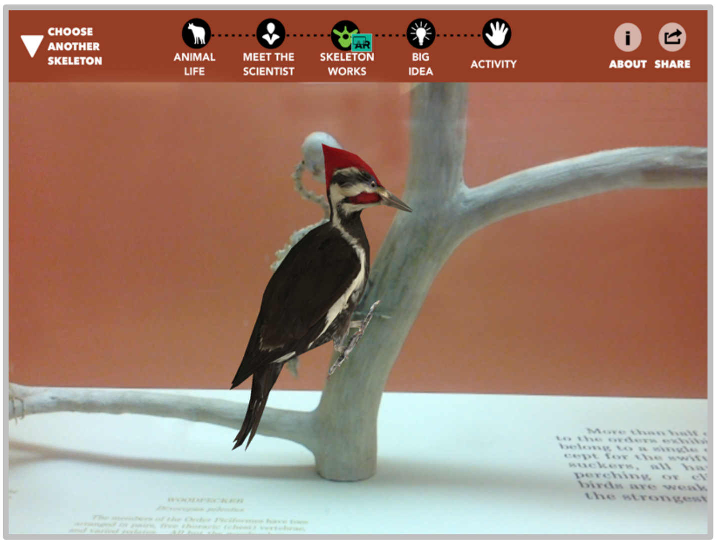

Figure 11 - Skin & Bones iPad screen capture of the Skeleton Works menu option for the Pileated Woodpecker, showing a frame of the AR content triggered from the skeleton. In the animation, the skeleton becomes fully fleshed and feathered; then the skull is isolated to illustrate the tongue mechanism specialized in catching insects.

Figure 12 - Visitor in the Bone Hall viewing the AR content for the Mandrill. Over the skeleton a 3D model of a fully fleshed animal is superimposed. As the visitor moves around the skeleton, the model readjusts to match the orientation of the specimen. Photo Credit: Nico Porcaro.

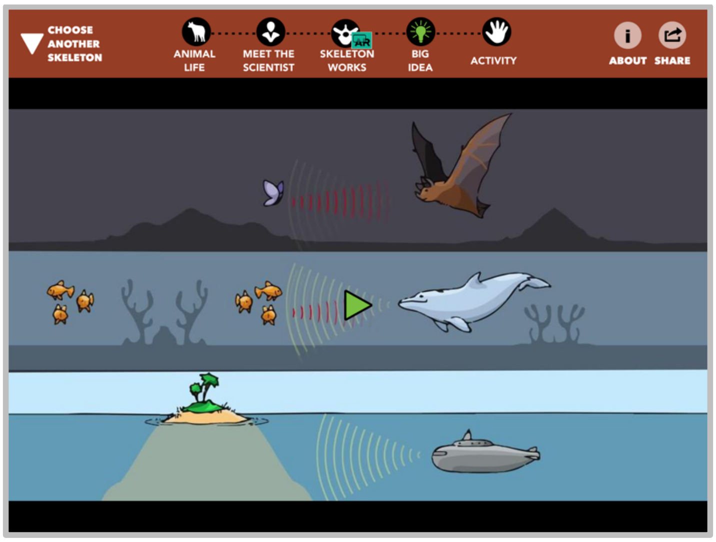

Figure 13 - Skin & Bones iPad screen capture of the Big Idea menu option for the Common Vampire Bat.

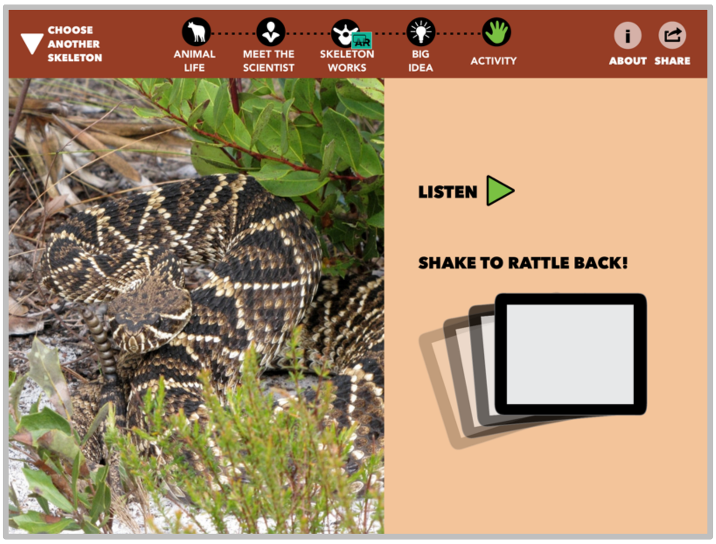

Figure 14 - Skin & Bones iPad screen capture of the Activity menu option for the Eastern Diamondback Rattlesnake.

Figure 15 – Skin & Bones label for the Baird's Tapir attached to the display case in the Bone Hall.

3.3. APP IN THE MUSEUM AND BONE HALL

Six promotional posters displayed along the Bone Hall walls, on stanchions and across one bench draw attention to the app. Smaller size posters were displayed at the information desks of the Museum and digital screens around the Museum promoted the app. To assist with navigation and usage of the app, vinyl labels were applied on the glass cases in front of the skeletons with the name of the animal and corresponding number to the map in the app (Figure 15, p.67). The presence of the labels and the text was subject to formative evaluation.

A companion website dedicated to the Bone Hall and Skin & Bones presents the history of the exhibition and how it has been enhanced through technology:
http://naturalhistory.si.edu/exhibitions/bone-hall

4. RESEARCH METHODOLOGY

This research adapted and implemented a framework for evaluating the UX of mobile AR services, and combined it with traditional visitor studies' ethnographic approaches to studying how the Visitor Experience is modified by AR technology. Using Skin & Bones as a case study, the methodology was designed to examine visitor behaviors in the exhibition before and after the digital intervention. Additionally, for research purposes, two versions of the app were developed to isolate AR as a variable, so one app containing the same content delivered the AR media as static images and videos and the other app included the full AR experiences.

The study that was conducted at the Bone Hall prior to developing the mobile app provided a baseline comparison to the later study (p.70). The remainder of the methodology included distributing the two research apps to the visitors in the Bone Hall and observing and tracking them, interviewing them or collecting their responses to a questionnaire (p.75). Here is also included a discussion of the pilot study that informed the selection of the methods and instruments through iteration (p.79) and the method for recruiting participants (p.70).

A parallel source of data gathering was through Google Analytics for Mobile Apps, a free analytics tool that tracks and reports aggregated usage from all individuals that download the app (p.81). Whereas the direct approach to data collecting at the Bone Hall returned a detailed picture of the experience of each individual sampled, the indirect approach with Google Analytics yielded aggregated data in amounts that would never have been possible to collect in-person.

The limitations of the research methodology are included (p.83) as is the process taken to analyze the data by coding it and applying statistical tests (p.84).

Besides the lead researcher, Diana Marques, there were 11 other research assistants involved to support the collection of data and serve as consultants. All of them completed human subject research training in compliance with the Internal Review Board of the Smithsonian Institution, and those directly responsible for data collection carefully followed the same protocol. The handling and storing of the data, and data analysis, were done exclusively by the lead researcher.

Participation in the project presented minimal risk to human subjects, all of whom partook voluntarily in the study anonymously and without any direct benefit other than experiencing a new tool for communicating the stories represented by the exhibition. There was a formal application of the project to the Smithsonian Institutional Review Board that gave the approval and authorization to conduct the study.

4.1. BASELINE STUDY

In April of 2013 the lead researcher and a research assistant conducted a small study in the Bone Hall with the purpose of gathering information about the Visitor Experience in the exhibition before the digital intervention. The data gathered by the baseline study was used to inform the production of Skin & Bones, and also serve as a reference comparison for the data that was collected after the app release.

The study took place for 13 weekdays, one-hour each day, starting at random hours during the Museum visitation period of 10:00AM-5:30PM (10:00-17:30). It did not involve interaction with the visitors, who were solely observed and tracked during their time in the Bone Hall. The person conducting the research session was positioned at one of the entrances to the Bone Hall and selected the third visitor that walked in. Acting quickly, she would follow the visitor unobtrusively and keeping a discreet distance, and take note of 1) the visitor's path by drawing it as a line on a map of the exhibition, 2) the display cases where the visitor stopped, 3) the duration of the stops (a stop was defined as the visitor not moving for at least three seconds and looking in the direction of the display), and 4) certain behaviors that might occur, such as the visitor taking a picture or calling the rest of the social group to discuss something about one display. Additionally, the date, entry and exit times, gender, estimated age, group structure (adult alone, adult couple, teen alone, teen couple, school group or family), group size and estimated age of companions were recorded. Once the visitor exited the Bone Hall, the researcher finished recording the data and repeated the procedure with the third visitor that entered through the opposite exhibition entrance.

The recording of the data was conducted digitally using an iPad and a combination of three apps: 1) Bento by FileMaker, which is a database software that was used to store the visitor's and her group information, date, enter and exit times, 2) Penultimate by Evernote, where the person conducting the research session used a stylus to draw the path of the visitor on the map of the Bone Hall, marking every stopping point and the duration of the stop in seconds, and 3) Metronome+ by Dynamic App Design LLC, which was used to count the time.

This method gives an indirect measure of visitors' interest in the exhibition using as indicators the number, location and duration of stops, and duration of visit. Monitoring behaviors, estimating age, and observing the accompanying group, was meant to understand the profile of the audience of the exhibition and helped plan for the later study.

4.2. SAMPLING

An in-exhibition-mobile-app study was conducted at the Bone Hall and involved the direct recruiting of participants. It took place between April 15 and August 14, 2015. The lead researcher and five additional research assistants took turns in conducting the protocol for data collection described below and in the following sections, and included in full in the Appendix A. The protocol was applied for 92 days (weekdays and weekends) for one-hour-and-a-half each day, starting at randomly selected hours between 10:30AM and 4:30PM (10:30-16:30), or 10:30AM and 6:30PM (10:30-18:30), according to the season – in the Spring months the Museum visitation hours are 10:00AM-5:30PM (10:00-17:30), and in the Summer months 10:00AM-7:30PM (10:00-19:30).

Potential participants in the in-exhibition-mobile-app study were selected among visitors that entered the Bone Hall through both entrances, by themselves or in small groups (up to five people), that appeared to be above 12 years-old and showed an interest in the displays by pausing in front of the skeleton cases, as opposed to walking through the Bone Hall as a passageway to other destinations. Intentionally the study avoided recruiting visitors that were part of large groups (organized tours, school groups, families with many members), even though the baseline study and previous visitor studies in the Museum indicated they are prominently represented in NMNH audience. Individuals in large groups usually conduct visits on a limited time schedule, it is not uncommon to find organized groups in the Museum that have one to two hours to see all of the exhibitions and are less likely to engage with particular exhibitions to the point of downloading a companion mobile app to have a more in depth experience. In addition, for such visitors, the choices made during the visit are expected to result from a collective agreement rather than individual preferences, which would interfere to a greater degree with the collecting of data later used to test the IPOP framework.

During the recruiting process, one researcher would approach the identified visitor using the designated consent language:

Good morning/afternoon, my name is –– and I am conducting a study here in the Museum. We have a new mobile app for this skeleton exhibition and are inviting the visitors to test it and give us feedback on their experience. If you would like to participate I will hand you an iPad and you can use the app as much or as little as you want; you can stop at any time. I will be around the exhibition, following along, and when you are done, just come see me. There is a 4-minute survey at the end I would ask you to fill in [for collection of quantitative data] */We will then have a little chat about it* [for collection of qualitative data]. *Would you like to participate?*

If the visitor did not understand the question, showing signs of disability or difficulty with the English language, or if the visitor declined to participate, the researcher added one entry to the Declined List. Each declined entry included the date, time, reason for declining if stated, the visitor's apparent age range, and gender.

If the visitor agreed to participate, she would be given a unique identification number (ID#) only known to the researcher, and receive a Museum owned iPad with either of the two research versions of Skin & Bones installed, the AR-version and non-AR-version. The Museum iPads handed out for this purpose were enveloped by a conspicuously large and bright blue case, that facilitated the handling of the device and protected it from concealed theft.

The researcher carried two sets of earbuds in case participants asked for them, but intentionally would not hand them out or make participants aware they were available. Informal observations indicated that visitors that are in the Hall using the app independently from the research study very rarely used audio assistance, despite the pop-up message upon opening the app that suggests to do so; either visitors are not carrying earbuds with them or choose not to use them if in the exhibition as part of a group, which might be deemed as unsocial. Therefore, handing out earbuds to the study participants would possibly bias the sample, and researchers decided to only deliver them if visitors asked if they were available and requested to wear them.

No information about the content or purpose of the app was provided, with the goal of reproducing, as much as possible, the situation of a visitor entering the exhibition and downloading the app to a personal mobile device and undertaking its use without assistance. The participant was then left to explore the exhibition on her own, while the researcher observed and tracked the visit from a distance. Once the participant finished, she was invited to fill in a self-administered online questionnaire or to sit and engage in a non-directed interview with the researcher.

4.3. TWO RESEARCH VERSIONS OF SKIN & BONES

For research purposes, two versions of Skin & Bones were developed, with the goal of collecting information about how the app was operated and what content was viewed by participants. One of the versions also acted as control by isolating AR as a variable to be examined.

Both versions differ from the publicly available Skin & Bones in the App Store by recording all actions taken by the users while interacting with the app. This was a feature coded into the application for this study. By connecting the research devices to the computer it was possible to extract lists of information with the selections made in each screen of the app, with the corresponding timestamps, which provided a record of everything the user did with the app and when. One example of the extracted data for one user is seen on Table 3.

In this example, the participant first selected the Swordfish from the map (A in Table 3) and then played the Meet the Scientist video (B), followed by the Skeleton Works AR experience (C); she then returned to the map and chose the Blue Catfish to see the Skeleton Works AR experience (D); back to the map she selected the Eastern Diamondback Rattlesnake Skeleton Works AR experience as she moved through the exhibition (E); and on the final return to the map she picked the Eastern Box Turtle to play the Animal Life video (F). None of the videos played by this user were watched for more than 80% of their duration (which would be an Action identified as “play-80”) and she also did not engage with any Activity. A video played at least 80% would have been considered as watched entirely, taking into account that the last 20% corresponds to the video credits.

Time	App Screen	Action	Selection
12:57:02	map	select	swordfish (**A**)
12:57:13	swordfish	menu	meet-the-scientist
12:57:13	swordfish	show	meet-the-scientist
12:57:17	swordfish	play	meet-the-scientist (**B**)
12:57:37	swordfish	menu	skeleton-works
12:57:37	swordfish	show	skeleton-works (**C**)
12:58:48	swordfish	menu	back
12:58:48	swordfish	back	
12:58:53	map	select	blue-catfish
12:58:58	blue-catfish	menu	skeleton-works
12:58:58	blue-catfish	show	skeleton-works (**D**)
12:59:37	blue-catfish	menu	back
12:59:37	blue-catfish	back	
12:59:50	map	select	eastern-diamondback-rattlesnake
12:59:53	eastern-diamondback-rattlesnake	menu	skeleton-works
12:59:53	eastern-diamondback-rattlesnake	show	skeleton-works (**E**)
13:00:38	eastern-diamondback-rattlesnake	menu	back
13:00:38	eastern-diamondback-rattlesnake	back	
13:01:26	map	select	eastern-box-turtle
13:01:47	eastern-box-turtle	menu	animal-life
13:01:47	eastern-box-turtle	show	animal-life
13:01:51	eastern-box-turtle	play	animal-life (**F**)
13:02:03	eastern-box-turtle	menu	back
13:02:03	eastern-box-turtle	back	

Table 3 - Example of one participant app usage. The data for each action includes a timestamp, the app screen where the action took place, and the selection of content made. Letter keys explained in the text.

Given that all selections are labeled with a timestamp, it was possible to know for each piece of content selected in the app the duration of viewing.

The two versions differ by how 3D digital models are displayed. One version uses AR to display the models and the other version does not and displays them either as static images or as video when the models are animated. Informational equivalence is achieved when all the information from one representation can also be inferred from the other representation and vice-versa (Larkin & Simon, 2010). Therefore, in a controlled study on AR such as this, creating informational equivalence between the two research versions of the app ensured that the potential differences observed between visitors using one and the other stemmed from the mode of technology conveying the content and not from the content itself.

Hereinafter the app in the AR condition that displays augmented content like the publicly available Skin & Bones is called "AR-version"; the other is referred to as "non-AR-version". The latter version does not require the device to turn on the camera and there is no direct interaction with the skeletons when displaying the content on the screen (Figure 16). Hence, the study had two subsamples, one consisting of participants that had the possibility of seeing augmented content, and another consisting of participants that had the possibility of seeing the exact same content, but not delivered through AR (hereinafter these participants are said to have seen AR-equivalent content).

Figure 16 - Comparison between the research AR-version (left) and non-AR-version (right) of Skin & Bones. With the AR-version, upon selection of the Mandrill Skeleton Works menu option the back camera of the iPad turns on and the 3D model is activated to overlap the specimen; with the non-AR-version, the 3D model displays on the screen without augmentation. Photo credit: Nico Porcaro.

Comparing the two subsamples allowed for establishing differences in the Visitor Experience influenced by the use of AR technology. These differences were analyzed in the 1) pattern of visitation, 2) viewing of content and preferences for content, 3) satisfaction with the visit and meeting of expectations, and 4) rating of the user experience.

The iPads handed to the study participants in the Bone Hall either had the AR-version or the non-AR-version installed and were alternated. On data collecting sessions where the non-AR-version was distributed, the posters in the exhibition that promote the download of the app and clearly illustrate its AR features, were covered. This prevented participants from being aware of and trying to find the technology in an app version that was the control for AR.

4.4. QUANTITATIVE METHODS

Observation and Tracking

Observation and tracking are some of the most established research methods in visitor studies (Santos, 2000; Yalowitz & Bronnenkant, 2009). They have great ability to analyze the engagement of visitors by recording the duration and path of the visit, the parts of the exhibition that function as attractants, and the individual and social behaviors elicited by the space, the collections, and interactions with other visitors. In this research, the observation and tracking of participants was central to the documentation of the visit using Skin & Bones, allowing to capture the pattern of visitation, behaviors and noted areas associated with decreased app usability.

To guarantee that observation as a research instrument provides reliable data, the researcher should outline in advance the expected behaviors so that they can be properly noted and coded. The researcher should also utilize a simple and dedicated method of recording the observations (Anguera, 1993). As described below and in the data collecting protocol (Appendix A), the mobile app Track'n'Time was employed, a tool developed by Oberg Research, LLC, dedicated to museum studies and customizable for the exhibition under study. The protocol was written by the lead researcher before the collecting sessions began and explained in detail to the research assistants along with how to operate Track'n'Time and how to conduct the observation and tracking of the participants with specifics on the behaviors to pay attention to and record.

The protocol was fundamental in the training of the research assistants involved with the quantitative data collection. Observation has the potential for inherent problems, namely reliability and exactness when it is performed by different data collectors within the same study (Deacon, Pickering, Golding, & Murdock, 2007). Having one uniform document to refer to assisted in avoiding that problem, as did the three to four initial training sessions where the lead researcher accompanied each assistant to demonstrate and standardize the procedure.

The observation and tracking of each recruited visitor in the Bone Hall started the moment she agreed to participate in the study, took the Museum iPad and was assigned an ID#. With Track'n'Time on a second iPad, the researcher recorded: 1) the participant's time at enter and exit, 2) crowd level at the exhibition, 3) gender of the participant, 4) all stopping points, in addition to the time spent at each stop, and 5) behaviors at each stop. There were 62 stopping points: 54 display cases, plus "standing" in any of the five rooms and "sitting" in any of the three benches (the 10 display cases in the rotunda were aggregated as one stopping point) (for reference, see the exhibition floor plan on Figure 3, p.55). There were eight behaviors monitored: "group selection," "talks about exhibition," "hands iPad to group," "calling others over," "takes picture," "reads labels/text panels," "app crash" and "couldn't operate AR". A description of each behavior is included in the Appendix A.

Data collectors followed the participants unobtrusively and kept a discreet distance during their session, and recorded their stops regardless of whether the participant was actively using Skin & Bones. The definition of a stop is a participant with both feet planted on the floor for at least three seconds in front of a display case, standing somewhere else in the exhibition not looking at a display, or sitting on one of the benches. A return to a previously visited stopping point did not count as an additional stop, but it was included in the total time. This definition of a stop in a museum exhibition has traditionally been used in visitor studies (Serrell, 1997) and was deemed appropriate for this setting, even though it has been argued that for exhibitions with large displays (e.g. aquariums and zoos, large scale installations, etc.), the planting of the feet should not be a requirement (Yalowitz & Bronnenkant, 2009).

Questionnaire

While observation and tracking are established instruments in visitor studies that measure behavior, questionnaires can probe more deeply into cognitive experiences. Museum professionals favor questionnaires as set of questions that retrieve information directly from visitors and contribute to describe the existing and potential museum audiences, their profiles, opinions, self-described experiences and preferences (Santos, 2000). In this research a questionnaire was used as an instrument to assess participants' 1) satisfaction with the visit and with the mobile app, 2) personal context by inquiring about previous visits to the Museum and to the exhibition, existing expectations for the visit, previous experience with mobile technology, 3) sociodemographic information, 4) app content preference, 5) rating of the user experience, and 6) rating in the IPOP framework.

The formulation of a questionnaire in the context of museum visitors as subjects has been discussed extensively (e.g., Fink, 2012; Korn, 1988). Authors emphasize the importance of the short length and simple phrasing of the questions that should take into account the respondent's educational level, and be clear by transmitting one idea only and avoiding obscure museum terminology. In this research, a pilot study (described next, p.79) was conducted, among other purposes, to guarantee that the questionnaire was appropriate to the visitors of the Bone Hall and not only it was well understood by them to validate the questions, but also gathered the information required to answer the research questions. Moreover, particular attention was given to the total number of questions and the time required to answer them to assure that participant time was not overly taxed, their patience exhausted or their answers rushed.

The questionnaire was distributed after the participants finished the visit and on the same iPad they had used to operate Skin & Bones. The questionnaire was accessed using the online survey software company, SurveyMonkey. The questionnaire can be found in full in the Appendix B exactly as it appeared online when filled in by participants. It is structured in four parts, each with different goals.

- Part one of the questionnaire – questions 1 through 9

Aimed to establish the individual's personal context by inquiring about previous visits to the Museum and to the Bone Hall, and about their level of comfort with technology. It addressed the participants' social context by asking who they were with while visiting the museum. It also measured participants' satisfaction by collecting information about the visit motives and expectations, ratings of the exhibition and app, and their intention to further explore Skin & Bones by downloading it to their own device.

- Part two of the questionnaire – questions 10 through 12

Included two multiple choice questions with the lists of the Skin & Bones animals and section headings for participants to select their favorites. In addition, there were corresponding open-ended questions for justifying those choices.

The last question in part two of the questionnaire is an adaptation of Olsson's measures for evaluating the user experience of mobile AR services (Olsson, 2013), as discussed previously (p.45). Olsson and collaborators' research led to a consolidation of 16 identified categories of experiences that are expected to be present in users' interactions with mobile AR. The 16 categories were further classified into six classes that represent higher levels of user experiences: 1) instrumental experiences, 2) cognitive and epistemic experiences, 3) emotional experiences, 4) sensory experiences, 5) motivational experiences, and 6) social experiences. To operationalize his theorization around mobile AR, the author translated each of the 16 categories into measures, formulated as statements to be used as Likert items to create a Likert agreement scale.

This research set out to adapt Olsson's methodology as an assessment tool to measure visitor experiences with AR within the context of visitors using Skin & Bones at the Bone Hall. Rather than constructing statements that name the technology directly – for instance, as suggested by the author under the category Surprise "browsing content as augmentation helps me find the most astonishing content" – a different approach was taken to focus the statements on the mobile app, which is tangible and familiar. For example, "it was amazing to use Skin & Bones." The purpose was to compare the level of agreement with the statements between participants who used the AR-version of Skin & Bones and had AR experiences, and those who used the non-AR-version of the app and saw AR-equivalent content, without naming the technology, which could lead to confusion among visitors that did not experience AR.

One further adaptation of the methodology was condensing the set of 16 statements into merely six, one per each higher level of user experience identified by Olsson. The resulting set of statements was: 1) "Skin & Bones made it easier for me to connect to the exhibition" (instrumental experience), 2) "Skin & Bones met my interest for knowing about the animals" (cognitive and epistemic experience), 3) "it was amazing to use Skin & Bones" (emotional experience), 4) "Skin & Bones did not hold my attention" (sensory experience), 5) "I do not want to share Skin & Bones with my friends" (social experience), and 6) "Skin & Bones made me want to discover more about the animals" (motivational and behavioral experience).

The use of reverse wording in the statements, i.e., phrasing some using the positive voice (1, 2, 3 and 6) and others using the negative voice (4 and 5), was intended to reduce acquiescence bias, which occurs when respondents agree to all statements in a straight-line fashion without considering the content of the statement. This and other considerations regarding the construction of the statements, resulted from an iterative validation process during the pilot study, described next.

Each statement in question 12 was rated as a seven-point Likert item (Strongly disagree/ Disagree/ Somewhat disagree/ Neutral/ Somewhat agree/ Agree/ Strongly agree). Opinions in the literature diverge regarding the use of seven-point versus five-point Likert items (DeVellis, 2012). Both alternatives are balanced in the number of positive and negative choices given to the participant, which is preferable for analyzing the data and determining a Likert scale (Blanche, Durrheim, & Painter, 2008), and both offer a middle value which gives respondents a neutral option that falls at the mid-point of the preference dimension (Sturgis, Roberts, & Smith, 2014). However, where supporters of seven-point items highlight better granularity, advocates for five-point items have concerns about respondents' indecision and feel that offering less choices is a more conclusive approach. This research opted for seven-point items to give participants added response options, which was seen as more flexible and friendlier in a museum environment (five-point items are sometimes regarded as being too forceful). In addition, since the questionnaire was distributed in written form (versus over the phone), there was not a concern that respondents forgot a higher number of options or were confused by them. A preliminary analysis with the pilot data confirmed a balanced distribution of answers along the seven Likert items.

- Part three of the questionnaire – question 13

Included a collection of 12 statements developed by Pekarik et al. (2014) as a subset of a longer form questionnaire by the same authors that consists of 38 items. The respondents declared how much they identify themselves with each statement by selecting between four options: Not me at all/ A little me/ Me/ Very much me. This instrument assigns to every respondent a score in each of the four IPOP dimensions – Idea, People, Object and Physical, as discussed previously (p.49) – and indicates the degree to which the individual tends to identify with that type of experience in comparison to all others who have been similarly scored. The authors affirm that preferences can be identified, i.e., an individual has a higher score in one dimension when compared to another, but they are not absolute. This scoring instrument was included in the questionnaire to categorize the participants according to the IPOP framework and later relate the data to the content categories they selected and the duration of engagement. The decision to use the 12 item subset versus the full 38 was part of the effort to keep the questionnaire at a reasonable size.

- Part four of the questionnaire – questions 14 through 17

Collected sociodemographic information such as residence location, age, education level and ethnicity. The phrasing of the questions closely followed questions included in audience studies conducted by the Smithsonian's Office of Policy and Analysis and in the NMNH Evaluation Framework, Metrics, and Protocols for Public Programs, Education, and Outreach (NMNH, 2012). Approximating the sociodemographic information collected in this research to the institutional legacy information allowed for a comparison of the audience composition in this study sample with audience profiles from the Museum's past.

Pilot Study

The pilot study consisted of 20 one-hour-and-a-half sessions of data collection in the Bone Hall during consecutive days between March 16 and April 4, 2015. It was conducted exclusively by the lead researcher with the goal of developing and fine tuning the methods and instruments to be used later in the in-exhibition-mobile-app study. 72 visitors were recruited and after outlying data was removed, the final set resulted in 61 data points.

Before the pilot study began, two groups of visitors had come to the exhibition to use Skin & Bones – one group was comprised of nine museum professionals from the United States Holocaust Memorial Museum, and the other group included 18 Smithsonian interns and fellows that were on a tour organized by the Smithsonian Office of Fellowships and Internships. By the occasion of these two visits, parts one and four of the questionnaire had already been developed and assembled with the preexisting part three; as such they provided good opportunities to test the efficacy and comprehensibility of the questions, which was confirmed. This confirmation of the tools led to the application of the incomplete questionnaire in the upcoming pilot study. For the pilot a preliminary protocol had already been developed to assist with the recruitment of participants, and their observation and tracking using the Track'n'Time app.

The purpose of the pilot study was predominantly to test the procedures and interactions of the researchers with the participants, understand the dynamics of the visitors using the app, guarantee that the data was properly retrievable, and identify areas for improvement. The pilot observation and tracking of these participants was a useful insight into the social interactions and exchanges that take place within the groups while using Skin & Bones, and led to additions to the list of behaviors to record, such as "group selection," "shows content to group" and "hands iPad to group." Occasional failures observed in triggering the AR experiences, also led to including "couldn't operate AR."

In parallel with commencing the pilot study was further work done to adapt the framework for studying the Visitor Experience with mobile AR to a set of six statements, which were to be included in part two of the questionnaire. To establish face validity of the statements, the lead researcher consulted with three experts in an iterative process. It proved to be a complex and significant exchange of perspectives, that took into close consideration the statements from the original framework and their description by Olsson, the appropriateness of the content of the adapted statements, the level of sophistication of the language, and the statements construction and sequence.

To test part two of the questionnaire in particular, the lead researcher recruited, observed and tracked, and then delivered the questions in print (instead of on the iPad) to 16 visitors in the Bone Hall. Importantly, participants were observed carefully while answering to detect hesitations. Occasionally certain statements were pointed to and participants were asked "*what do you think this means? What are we trying to find out with this?*" The validation process was revealing and led to adjustments in the statement that assesses the level of emotional experience – from "it was surprising to use Skin & Bones" to "it was amazing to use Skin & Bones."

4.5. INTERVIEWS

To complement the quantitative data collected by the research versions of Skin & Bones, the observation and tracking, and the questionnaire, 15 interviews were conducted with visitors to the Bone Hall. In 10 interviews the visitors had used the AR-version of the app, and in the remaining five interviews the visitors had used the non-AR-version.

Participants selected for interviewing were recruited to use the app and share their experience in an identical way to visitors that filled in the questionnaire. However, unlike the questionnaire where the researcher always asked only one participant to answer the questions, with the interviews the researcher addressed the entire group and collected opinions from all the members that wished to share.

The recruitment took place during 6 weekdays in May and June of 2015, for one-hour-and-a-half each day, and with random starting times during Museum visitation hours. All of the interviews were led by the same research assistant, under the observation of the lead researcher, and recorded by a small non-intrusive audio recording device.

The general goal of the interviews was to understand visitors' broader perceptions of the app and their experience with it during the visit, particularly the use of AR if they came across it. Thus, the approach taken was to conduct the interviews in an open-ended manner prompting the participants by saying simply "*tell me about it*" and letting them freely express their thoughts.

There were a few themes that the interviews were intentionally exploring. If they were not touched on by visitors' first response to the initial prompt, the research assistant would ask a question, always in a conversational and relaxed manner as recommended by Doering (1999a). The themes were 1) participants' familiarity with using apps and particularly with using apps in museums, 2) their experience with Skin & Bones, the features used, reasons for giving preference to those features and feelings about them (enjoyment, frustration, distraction, etc.), 3) suggestions for improving Skin & Bones and thoughts on target audience and social dimension of the app (i.e., solo museum visit, family group, school group, etc.), 4) comparison between the experience of visiting the Bone Hall with Skin & Bones and visiting another museum exhibition without digital enhancement, and 5) presence/absence of AR during the visit and description of its influence if the participants came across it.

As the number of interviews approached 15, visitors' perceptions regarding most of the themes became recurring and the decision was made to cease the collection of qualitative data.

4.6 APP ANALYTICS

Skin & Bones is equipped with Google Analytics for Mobile Apps SDK, hereinafter called GA, a cost-free analytics tool developed by Google that can be integrated into an app's code, and tracks and reports its usage. Mobile analytics tools are widely applied by marketers and developers to assess and improve app sales and performance. However, this research used GA to study the user profiles and behaviors, and user engagement with Skin & Bones content. Any user that downloads the app and opens it at least once, regardless of the location, becomes part of the GA dataset, but the information about that user cannot be accessed separately from the information gathered from other users. The GA online dashboard only displays aggregated data, across categories for any selected period within Skin & Bones' lifetime. The most significant categories for this research were 1) audience: number of users and their demographics (place of origin, language), and 2) behavior: session duration, screen views and events.

GA events are used to collect data about interactions with particular pieces of content within apps and require adding tracking code during the app development. Each GA event that was coded in Skin & Bones is described by a category, an action and a label. The goal of coding events was to monitor the viewing of videos, activities and AR experiences by all of the users of the app. Table 4 (p.82) lists Skin & Bones events.

Every time a user presses play to watch a video (e.g. Vampire Bat Animal Life), or triggers an AR experience (e.g. Vampire Bat Skeleton Works) or completes an activity (e.g. Vampire Bat Activity), GA counts one unit of the corresponding event. If the video played is watched for more than 80% of its duration, GA counts one Play event plus one Played 80% event. If the user is identified with one Played 80% event, she is considered to have watched the entire video.

Event Category	Event Action	Event Label
VIDEO	PLAY PLAYED 80%	Vampire Bat Animal Life
		Vampire Bat Meet the Scientist
		Vampire Bat Big Idea
		American Bison Animal Life
		American Bison Meet the Scientist
		American Bison Big Idea
		Mandrill Animal Life
		Mandrill Meet the Scientist
		Mandrill Big Idea
		Steller's Sea Cow Animal Life
		Steller's Sea Cow Meet the Scientist
		Baird's Tapir Animal Life
		Baird's Tapir Meet the Scientist
		Baird's Tapir Big Idea
		Anhinga Animal Life
		Anhinga Meet the Scientist
		Pileated Woodpecker Animal Life
		Pileated Woodpecker Meet the Scientist
		Pileated Woodpecker Big Idea
		Brown Kiwi Animal Life
		Brown Kiwi Meet the Scientist
		Brown Kiwi Big Idea
		South American Bullfrog Animal Life
		South American Bullfrog Meet the Scientist
		Eastern Box Turtle Animal Life
		Eastern Box Turtle Meet the Scientist
		Eastern Diamondback Rattlesnake Animal Life
		Eastern Diamondback Rattlesnake Meet the Scientist
		Eastern Diamondback Rattlesnake Big Idea
		Swordfish Animal Life
		Swordfish Meet the Scientist
		Swordfish Big Idea
		Blue Catfish Animal Life
		Blue Catfish Meet the Scientist
AR	TRIGGERED	Vampire Bat Skeleton Works
		American Bison Big Idea
		Mandrill Skeleton Works
		Steller's Sea Cow Skeleton Works
		Anhinga Skeleton Works
		Pileated Woodpecker Skeleton Works
		Eastern Diamondback Rattlesnake Skeleton Works
		Swordfish Skeleton Works
		Swordfish Big Idea
		Blue Catfish Skeleton Works
ACTIVITY	COMPLETED	Vampire Bat Activity (Level 1)
		Vampire Bat Activity (Level 2)
		Pileated Woodpecker Activity
		Eastern Diamondback Rattlesnake Activity
		Swordfish Activity

Table 4 - GA events that were coded in Skin & Bones to monitor user content viewing.

For this research, GA data is relevant for comparing the use of Skin & Bones between individuals using the app outside of the physical Museum and those that download and use it during a visit to the Bone Hall. This information contributes to a better understanding of app usage and behaviors in a museum setting and how they might differ when the user is in a different physical location. However, it is relevant to remember that the app content viewing outside of the Museum does not comprise AR[5] – in GA terms, the event action "AR Triggered" could only be recorded in sessions taking place in the Bone Hall. The other event actions like "Video Play", "Video Played 80%" and "Activity Completed", could take place anywhere. By default, an AR event recorded on GA locates the user in the Bone Hall.

The user location identified by GA (up to the city level) is in fact the place where the internet service provider is and not where the user is operating the device; i.e., a visitor browsing Skin & Bones in the Bone Hall, using her own mobile data plan, instead of the Museum's Wi-Fi, is interpreted by GA as not being in Washington DC if the service provider is located outside of the city. Therefore, as a first step to separate the users based on their actual location, two GA filters were created (upon the public release of the app, since filters do not operate retroactively). The first criterion used to separate in-gallery users from external users is the Smithsonian Wi-Fi network IP address that is identified by a unique number sequence. An "SI Traffic Only" filter retrieved GA data from individuals connected to the SI-network. Visitors to the Bone Hall could use free Wi-Fi provided by the Museum, a service made available in the Bone Hall for this project ahead of rolling out the service across the Museum. The other "External Traffic Only" filter retrieved all other data, i.e., from individuals connected to any other Wi-Fi network or utilizing their own mobile data plan. The data collected by the first filter is, with very few exceptions, from individuals using the app in the exhibition; the data from the second filter includes a mix of individuals outside of the exhibition (using Wi-Fi and mobile data plans) and individuals in the exhibition (on mobile data plans). During the analysis of GA data described later (p.88), further steps were taken to parse the external traffic data into onsite and offsite users.

4.7 LIMITATIONS

The tool initially selected to monitor content viewing was Lookback, a dedicated user experience research platform that video records the device screen to capture users' every action. Lookback also activates the camera and microphone to register facial expressions and record voice. However, Lookback, which was in beta development, proved to be incompatible with Skin & Bones as it caused repeated crashes of the app. The best alternative to collect the

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[5] This is true for the first version of Skin & Bones which this research pertains to. The second version of the app, released in March 25, 2016, offers the possibility of printing pictures of the skeletons, to activate the augmented content outside of the Museum.

user behavior for content viewing data was to have that feature coded into the research versions of Skin & Bones, which made it possible to export the data into Excel spreadsheets (as described previously, p.72). With this method hard coded into the app, all of the actions taken by users were collected but participants' facial expressions and comments could not be monitored.

An additional factor influencing data collection was the crowdedness of the Bone Hall. At peaks of visitation, mostly in summer months, there were several days that research assistants were scheduled to be in the exhibition recruiting participants, but could not conduct their sessions given the extreme number of visitors. Additionally, on more crowded days there was a higher decline rate for participating in the study.

The crowds at the Bone Hall also interfered with the speed of the Wi-Fi connection. Even though accepting Smithsonian terms in an agreement screen is a required step for visitors to access the network, their mobile devices were scanning the environment for Wi-Fi services and had the effect of clogging the network. Each of the two Wi-Fi access points in the Bone Hall can support around 60-70 devices and at times there were more than 100 devices "connected". With extreme numbers of people in the same space, and the majority of them carrying mobile devices, the internet speed was often decreased.

4.8. DATA ANALYSIS

Coding

Whereas the observation and tracking, and the questionnaire, were methods conducted with commercially available tools, the app usage was monitored through a custom coded feature in the research versions of the app that allowed for retrieval of lists of menu options in the app, such as the example presented on Table 3 (p.73). Thus, the data sources yielded different levels of data readiness for statistical analysis – the output tables from the observation and tracking, and from the questionnaires, did not require extended restructuring, but the app usage data involved a thorough and prolonged process of coding, described below.

The data for each user was analyzed individually and filtered in Microsoft Excel for the actions considered significant for the study – play, play-80, show AR and show activity; i.e. each user was assessed for 1) every video played, and of those which were played more than 80%, 2) every AR experience seen, and 3) every activity completed. Using the timestamps, it was possible to calculate the amount of time the user spent on each action. Every action that lasted less than three seconds was disregarded. If a user did the same action more than once, for instance watched the same video twice, the partial times were added to reflect the total time spent with that particular piece of content.

The information collected from participants that used the AR-version of Skin & Bones made it possible to discriminate which ones actually selected and saw AR experiences, as using the AR-version does not guarantee a user will trigger AR. Similarly, among the participants that used the non-AR-version which ones selected and saw AR-equivalent content was assessed. Additionally, the app usage data was cross-tracked with the data gathered through observation and tracking, allowing for the recognition of situations where the user opened app screens that led to an AR experience, but could not in fact have seen the augmented content because at that point in time she was not in front of the correct display case in the Hall. Both data collection methods complemented each other in a useful way to identify confidently which content every participant saw and for how long.

Also relevant to the discussion is the processing of IPOP related data. Part three of the questionnaire aimed to assign to every respondent a score in each of four IPOP dimensions. To calculate the scores, the method employed by Pekarik et al. (2014) was used. Respondents rated the answers for each of the 12 statements as Not me at all/ A little me/ Me/ Very much me, and these were recoded as 1 through 4, respectively. Given that each statement is associated with one of the four dimensions – e.g., "I like to bring people together" is associated with the People dimension – every participant is attributed a total score in each dimension. Those totals are then run through an existing algorithm that calculates the z score, which is the relationship of each individual's four scores to the average of scores of the entire population that has taken the IPOP questionnaire. The z scores in each dimension range from -4 to +4 and are distributed in a bell curve with a mean of zero. A preference is identified this way, that is to say, a person has a higher score in one dimension than in another, but it isn't absolute; the scores are points on a continuum established by comparison with everyone in the dataset. If one person scores high in more than one dimension, she is considered to be one-dimensional or multidimensional dependent on the scores differing by more or less than 0.2, respectively.

Statistical Tests

All of the statistical tests in the study were conducted with the software IBM SPSS Statistics, and following the procedures described by Marôco (2014) and on the online statistics platform Laerd Statistics (A. Lund & Lund, 2015b).

The descriptive analysis of the study variables that included, among other tests, the Shapiro-Wilk test for normality, indicated that most did not meet assumptions required to be examined with parametric tests. Many variables are qualitative, either nominal (e.g. has the participant been to the Museum before – yes/ no) or ordinal (e.g. rating of the overall experience in the Bone Hall – poor/ fair/ good/ excellent/ superior). Other variables are continuous, like age or visit duration, and do not have a normal distribution, given that most Museum visitors tend to be within a certain age range and take visits of short or medium duration. Therefore, nonparametric tests were more appropriate to apply to the data.

Since the research design allowed the isolation of AR as an independent variable, the underlying approach to some of the statistical tests was to determine whether there were differences between two independent groups – "saw AR" and "saw AR-equivalent" – for several dependent variables from observation and tracking data, questionnaire data, and app usage data. To conduct such comparisons, the most applicable test is the Mann-Whitney U test, a rank-based nonparametric test that can be used to determine if there are differences between two independent groups regarding one dependent, continuous or ordinal variable (A. Lund & Lund, 2015a).

The same group comparison approach was taken with the IPOP related data, utilizing two methods in parallel. In the first method, the five groups of the independent variable IPOP Main Dimension (participants identified as Idea, People, Object, Physical and Multidimensional) were compared regarding potential differences in the content they viewed in the app (e.g. number of Meet the Scientist videos each group saw, duration of Activities each group played, etc.). For this comparison, the Kruskal-Wallis H test was employed. As with the Mann-Whitney U test, the Kruskal-Wallis H test is a rank-based nonparametric test used to determine significant differences between groups, except it compares two or more groups of the independent variable, as opposed to only two groups as the Mann-Whitney U test.

The second method used to analyze IPOP data grouped individuals that saw a greater number of pieces in one of the five menu options than would be expected if they were selecting at random; then looked at the distribution of the variable IPOP Main Dimension within each group. Parsing the IPOP related data in these two ways assesses the predictiveness of the framework for user preferences. To create the groups of individuals, their entry point to the Bone Hall (fish room or mammal room) was accounted for and the number of content pieces in each menu option for the first five Skin & Bones animals the participant could have encountered. For instance, entering the exhibit at the fish room the participants could choose to stop at the Swordfish, Blue Catfish, Eastern Diamondback Rattlesnake, Eastern Box Turtle and South American Bullfrog, which offer in total five Animal Life items, five Meet the Scientist items, three Skeleton Works items, two Big Idea items and two Activities. The probability of encountering content pieces – based on the frequency of occurrence – in each menu option were compared with the actual content viewed to assess the participants' preferences.

Additionally, a multivariate approach to the analysis of all the study data was taken, to simultaneously analyze all the dependent variables and their potential combined effect. Seeing the elevated number of dependent variables in the study, the approach was done in two steps: first, a dimension reduction was performed to the data aiming to decrease the large set of variables into a smaller set that accounted for most of the variance in the original variables; then, the reduced data was used to inform about the similarity and dissimilarity between participants, permitting their grouping into clusters that represent individuals with common features.

The reduction of the data was done with a Categorical Principal Component Analysis (CATPCA). The principal components are the resulting independent variables from linearly combining the original variables, and they summarize most of the initial information. When the original variables are of qualitative nature (nominal or ordinal), or a combination of qualitative and quantitative, the appropriate test is a CATPCA (as opposed to a PCA exclusively used for quantitative data), which numerically quantifies the categories in the qualitative variables and makes possible the application of standard analytical methods (Marôco, 2014). To apply the CATPCA the quantitative variables in the study were recoded into categorical variables to homogenize the inputted data onto the test. The decision on the number of components to retain is based on the following criteria: 1) the eigenvalue-one criterion – an eigenvalue less than one indicates that the component explains less variance than a variable would and hence should not be retained; 2) examining the proportion of variance explained by each component individually and the cumulative percentage of variance explained by a set number of components – as the component number increases, each subsequent component explains less of the total variance; and 3) examining the scree plot and retaining the components before the inflection point of the graph, given that the inflection point represents where the graph begins to level out and subsequent components add little to the total variance.

The extracted principal components were in turn the variables with which a Hierarchical Cluster Analysis was run. This test created homogeneous clusters of participants based on their similarities with each other, and dissimilarities towards participants in other clusters. There are numerous ways to measure similarity/dissimilarity and also different clustering methods, hence it is common procedure to run different combinations to examine which provide the more consistent results for the study data set (Marôco, 2014). In this study, Ward's method used with a squared Euclidian distance as a dissimilarity measure proved more effective in producing homogeneous clusters through visual inspection of the dendrogram and analysis of each cluster against the original variables. Ward's method is set apart from other agglomerative clustering methods in that it is based on a sum-of-squares criterion, producing clusters that minimize within-group dispersion.

Interviews

The audio recordings of the 15 interviews were transcribed and a first stage of analysis focused on finding general categories that emerged from the data – for instance, quotes were extracted about the comparison between the experience of visiting the Bone Hall with Skin & Bones and visiting another museum exhibition, and other quotes on user's perception of the app. The categories that emerged from this approach were then checked internally and compared across categories to simultaneously find sub-categories and reflect if top-level categories should be merged.

Google Analytics

As mentioned, the GA online dashboard gives access to different categories of aggregated data for any selected period within Skin & Bones' lifetime, and exports the reports according to the customized searches and filtering. Therefore, reports and graphs were generated pertaining to user and device information. One caveat about GA data is the data should not be analyzed assuming data is exact, given the somewhat uncertain nature of data retrieved from analytics tools, and considering that GA does not apply its algorithms to the entire dataset but instead uses a sampling process that is not disclosed. For instance, when filters are applied, filtered metrics do not necessarily add up to reflect the total metrics. Therefore, the results are best interpreted as trends and should be used for comparison purposes only.

Data segments were defined to study with more precision the GA events data that is related to content viewing and behaviors with the app. Segments can isolate and analyze subsets of the data, according to customizing criteria and when combined with the internal and external traffic filters that were created for the app (described previously, p.81), allowed for discriminating behavior profiles of Skin & Bones users inside and outside of the Bone Hall.

- Segments "visitation summer hours" and "visitation winter hours" isolated data that was collected by GA while the Museum was open, in the summer (10:00AM-7:30PM/10:00-19:30) and during the rest of the year (10:00AM-5:30PM/10:00-17:30). When used in combination with the internal traffic filter, the data that reflects engagement with videos, AR and activities, assured the data was generated from users while in the exhibition (data segment represented in red in Figure 17).
- Segments "non-visitation summer hours" and "non-visitation winter hours", isolated data collected for when the museum was closed. When used in combination with the external traffic filter, the content viewing profiled is of users from outside of the exhibition (data segment represented in blue in Figure 17).

This filtering and segmentation method does not analyze data pertaining to *all* Skin & Bones users for a certain period of time, and there is no reliable information regarding the total number of individuals that downloaded and used the app in the Bone Hall versus the total number of those who did it outside of the Museum. However, it does circumvent the problem associated with the identified user location (as described previously) GA does not actually locate the device but instead locates the internet provider). This method isolates data from a subsample of users that were surely at the exhibition and data from a subsample of users that were guaranteed to be outside of the Museum, which provides the opportunity to compare their content viewing and overall profile.

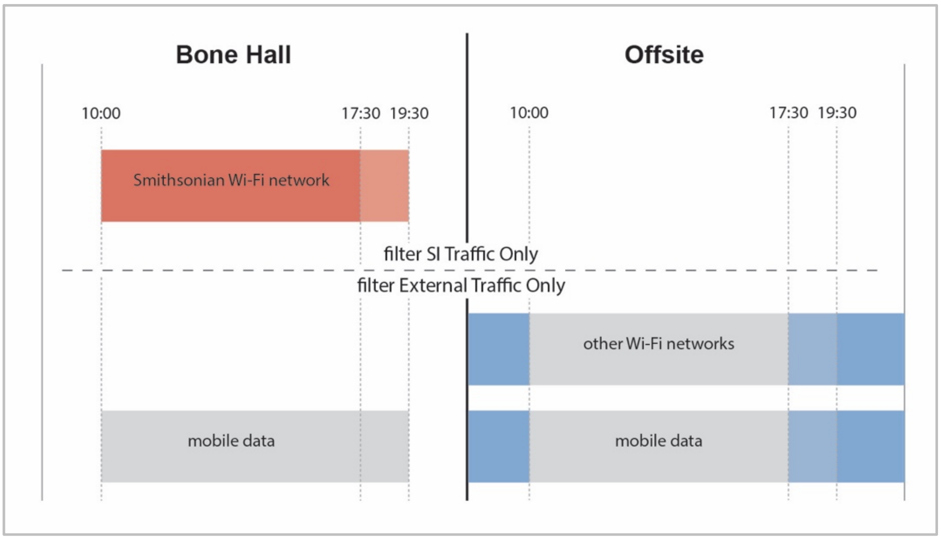

Figure 17 – Representation of Skin & Bones users in the Bone Hall and offsite, and the two options of internet connection, using Wi-Fi or mobile data. The filter "SI traffic only" combined with the segment that isolated data collected during open hours retrieved information regarding users in the Bone Hall (highlighted in red). The filter "external traffic only" combined with the segment that isolated data collected during closed hours retrieved information regarding users offsite (highlighted in blue).

IV. RESULTS & DISCUSSION

This research set out to contribute new findings to the existing literature and knowledge on the effects of mobile AR technology on the Visitor Experience within museum exhibitions. In particular, a decades-old exhibition was chosen as the study environment since no other technology was available at the exhibition. The primary focus is to examine the extent to which the use of mobile AR technology modifies the Visitor Experience, and to assess how the technology could reinvigorate an antiquated exhibition for visitors through a remaking of the visit.

Additionally, the research utilized the case study of an AR mobile app to assess different aspects of the production and implementation of the technology in a museum setting. Namely, 1) the predictive power of the IPOP theory of experience preference, which was the framework used for structuring content categories and developing the app content, 2) the model of combining in-gallery and offsite use into the design of the app, and 3) the concerns and challenges identified in the literature.

This chapter analyzes and discusses the outcome of the three studies conducted with respect to the goals of the research. First the participant samples of the studies are described (p.92): 1) visitors that were observed and tracked during the baseline study in the Bone Hall in its original, pre-digital condition, 2) participants recruited in the in-exhibition-mobile-app study to use the mobile app Skin & Bones in the exhibition, and 3) every user that engaged with the app, both at the Bone Hall and outside of the Museum that were included in the all-users study based on GA data.

Second, in this chapter the results of the analyses according to the research questions are laid out and discussed, beginning with the examination of the Visitor Experience with mobile AR technology in the Bone Hall (p.95), and followed by the exploration of the effects of the digital reinvigoration of the antiquated exhibition (p.116).

Finally, discussions of the data analyses are included as they pertain to the use of the IPOP framework for structuring and developing the app content (p.123), and the production model adopted by the case study (p.130) along with the assessment of some of the concerns and challenges identified in the literature (p.137).

1. SAMPLE DESCRIPTION

- Baseline study

During the 13-day baseline study, in the pre-digital condition, 128 visitors were observed and tracked as they went through the Bone Hall. The sample is composed of 61 males and 67 females, with estimated ages from under six years-old through 65+ years-old. The most frequent estimated age range is 41-50 years-old (16.7%), followed by 31-40 years-old (14.2%). Families (32.5%), school groups (20.6%) and adult couples (15.9%) are the most common group structures.

- In-exhibition-mobile-app study

During the 92-day in-exhibition-mobile-app study, 525 visitors were asked to participate, of which 231 agreed, yielding a participation rate of 44%.

Of the 294 visitors that declined to participate, 160 are males and 134 females, in the estimated age ranges of 21-30 years-old (13.6%), 51-60 years-old (8.8%), 41-50 years-old (7.5%) and 31-40 years-old (7.2%). The majority did not give a reason for declining (61.9%), but those who did attribute their refusals to shortage of time (23.1%) and difficulty with the English language (3.4%). Other less frequent explanations were lack of technical skills and interest in technology, no intention to see the exhibition (looking for the restroom, the cafeteria, a group member, etc.) or crowdedness of the Hall.

From the set of 231 visitors that agreed to participate, 32 data points were removed for various reasons – some visitors were observed and tracked but failed to fill in the questionnaire at the end of the visit, others changed their mind about participating halfway through, etc. – resulting in a final data set of 199 individuals. 102 participants used the research AR-version of Skin & Bones, and 97 used the non-AR-version of the app.

The questionnaire was used to collect sociodemographic information to construct a profile of the participant sample. On average, participants took 0:04:51 to complete the questionnaire. Among the 199 participants there were 96 males and 103 females. Participant ages are unevenly distributed across four groups, 21-30 years-old (35.7%), 31-40 years-old (16.8%), 16-20 years-old (15.1%) and 41-50 (13.5%) years-old. Samples of other age ranges are smaller. It is worth noting that a sampling criterion was to only approach visitors that appeared to be 12 years-old or more in compliance with U.S. Government rules regarding the privacy of children, which resulted in an underrepresentation of an age range that frequently visits the Museum.

By far, the sample was skewed toward Caucasian ethnicity (74.2%), with a much smaller representation of Hispanics (6.6%), Black/African Americans (2.5%) and other ethnicities such as Chinese and Native American. The majority (58.7%) had bachelor's degrees or graduate/professional degrees, and were from U.S. states outside of the greater Washington DC region (73.6%) or from another country (18.3%). Overall, this sociodemographic profile is closely representative of the population that regularly and voluntarily visits the Museum, which is known from decades of visitor studies at the Smithsonian as described previously (p.52).

The questionnaire also established the individual's personal context regarding previous visits to the Museum and the Bone Hall, the visitor's motives for the visit and group composition. Moreover, there was an inquiry about the participant's level of comfort with technology. Of the 199 participants, 40.4% had been to NMNH before, yet only 21.9% had visited the Bone Hall previously (or remembered visiting the Hall). Due to the sampling criterion of not recruiting individuals from organized school and tour groups, the great majority of participants were either in company of friends and/or family (75%), or by themselves (23.5%). The reasons given by participants for being in the Bone Hall included being on a general visit to the Museum (85.6%), or they intended to see something else in particular in the Museum and happened upon the Bone Hall (12.3%); none were there to use Skin & Bones and only 3 (1.5%) said they actually planned to visit that exhibition. As far as the participants' level of comfort with technology, 90.5% placed themselves on the comfortable end of the scale, either being "comfortable" (74.9%) or "somewhat comfortable" (15.6%).

In addition to the participants that filled in the questionnaire, the in-exhibition-mobile-app study included interviews with 15 visitors. The interviewees are distributed across the following group structures: five families, most with two parents and 2-3 teenagers/young adults, five adult couples, four single adults, and one single teenager who was in a larger teenager group visiting the Bone Hall but participated in the study and was interviewed by himself.

The interviews covered participants' previous experiences with using apps in museums, and with few exceptions, most had not used an app in a museum setting before. Some were unaccustomed to using apps at all, or they only use them to accomplish daily tasks, such as banking, navigation, or social media.

> "*I'm here for a convention, so I use my app at the convention site*."

> [Do you use apps?] "*Facebook, texting. Using a lot of google apps*" [Do you download apps for the places you go visit?] "*No, not at all*."

> "*I have an iPhone 6 and use apps all the time. But I've never used an app in a museum before*."

- All-users study

Unless otherwise noted, GA data pertaining to all users of Skin & Bones concerns the first year of its lifetime (January 13, 2015-2016). In that period, Skin & Bones had 12,099 new users[6] and Figure 18 shows their weekly distribution. As might be expected, the first week after the release saw the greatest number of users, the result of novelty, news media and museum professionals' that were aware of and had been waiting for the app to be released. Those earliest higher user numbers were only achieved again in the first two weeks of April, when the National Cherry Blossom Festival took place, an annual event that draws more than one million tourists to Washington DC, and spills over to the other public attractions in the city such as NMNH. Additional peaks in user numbers are equally the result of higher visitation in the Museum around the holidays for Thanksgiving at the end of November and Christmas at the end of December. One exception was a peak resulting from media attention, during the week of February 15-21 when a favorable, full-page app review was published in the Sunday Magazine from the Washington Post newspaper. Overall, the number of users is consistent to what would be expected in proportion to museum visitation. The primary target audience is visitors to the Bone Hall, and it is predominantly there that the app was advertised with a few signs.

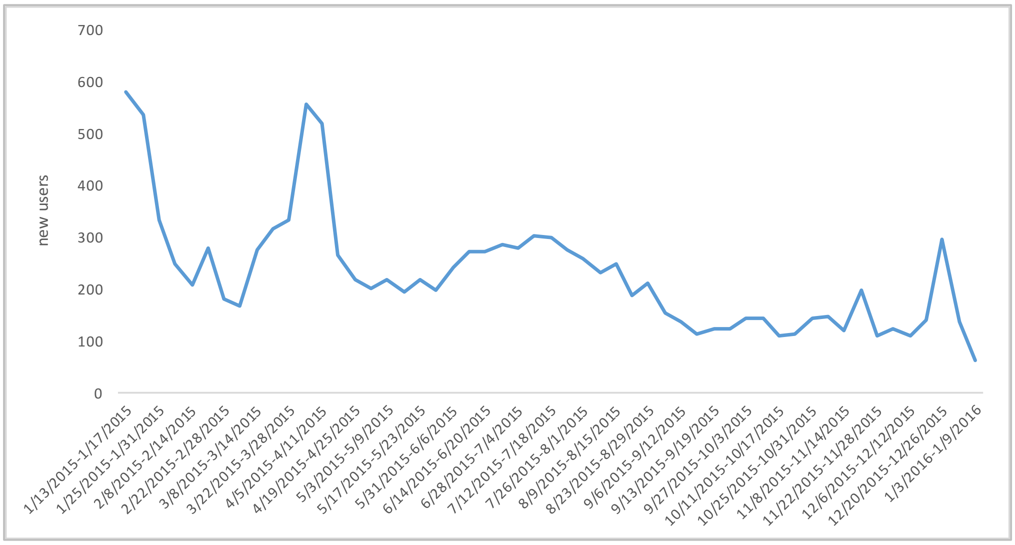

Figure 18 - Distribution of Skin & Bones new users across the first 52 weeks of the app's lifetime.

The great majority of users (91.3%) were located in the United States, with a minority presence in the UK (1.1%), Canada (0.9%) and Germany (0.6%), with several other countries accounting for the remainder. Not surprisingly, the mobile device languages detected were primarily English, followed by Spanish and German, with other languages minimally represented.

[6] GA definition of new users is "the number of first-time users during the selected date range". Even though it would seem coherent that the number of new users is the number of app downloads, for reasons explained in the data analysis section, and for other reasons discussed in the literature (see for example *https://www.optimizesmart.com/understanding-users-in-google-analytics/*), it is not reliable to do so. For example, for the same period of time, iTunes Connect – Apple's platform for uploading and managing mobile apps – indicates there were 10,321 units of Skin & Bones downloaded.

2. AUGMENTED REALITY AND THE VISITOR EXPERIENCE

The literature review mentioned aspects of the visit to a museum exhibition that have been considered fundamental by different authors in shaping the Visitor Experience. Visitor satisfaction and meeting of prior expectations are among them. This research not only applied methods to study these aspects, it also monitored several others and employed a framework from the UX field of study that are appropriate for analyzing visitor behavior in relation to technology.

The first question to investigate was phrased as "to what extent and in what specific ways does the use of mobile AR technology in a museum exhibition modify the Visitor Experience?" It was hypothesized that the Visitor Experience of visitors that use a mobile AR app within an exhibition is more positive than the Visitor Experience of those that visit without using the augmented technology.

In order to test the hypothesis, data was collected on participants that used the mobile app in the exhibition. During the in-exhibition-mobile-app study participants were alternately given one of the two research versions of Skin & Bones – the AR-version with augmented content or the non-AR-version with the same content, but without augmentation. Comparing the group of participants that used the first (n=102) with the group of participants that used the second (n=97) was the starting point of the investigation that isolated AR as an independent variable.

Ironically, the content viewing data extracted from the iPads revealed that not all of the participants in the two groups actually experienced AR content or AR-equivalent content. Some made menu options that led them to watch videos and/or play activities only. Coincidentally, the number of participants that used the AR-version of the app and actually saw AR is the same number of those that used the non-AR-version and saw AR-equivalent content – 75 participants. These two groups are sociodemographically very similar and comparable in terms of the personal context of the participants. The data generated by these 150 participants is the basis for comparison analyses conducted to answer the first research question and from which other analyses derived. In the following discussion, the 75 participants who saw AR content are referred to as group A and the 75 participants who saw AR-equivalent content are referred to as group B.

Specific differences between group A and group B were investigated regarding their 1) pattern of visitation, 2) viewing of content and preferences for content, 3) satisfaction with the exhibition visit experience, with the mobile AR system, and congruence of experiences and expectations, and 4) rating of the user experience. The results from comparing these metrics are presented and discussed next.

2.1. PATTERN OF VISITATION

The pattern of visitation of participants in the in-exhibition-mobile-app study was measured through visit duration, number of stops, duration of stops and specific behaviors, all of which were recorded during participant observation and tracking.

The number of times a visitor stops by display cases in an exhibition and the duration of those stops are common indicators of interest, and in turn influence the overall duration of the visit. A visitor that is engaged with an exhibition is expected to stop more often and for longer periods taking in the information and consequently her visit duration is expected to be higher than a visitor that is less interested. Table 5 summarizes the mean and median values of these metrics for groups A and B and shows how the two values of central tendency are consistently higher in group A. Participants who experienced AR had lengthier stays in the Bone Hall, stopped more often and for longer than participants who saw the same content without augmentation.

	group A		group B	
	Mean	Median	Mean	Median
Visit Duration	0:17:00	0:14:00	0:15:00	0:13:00
Total Number of Stops	12	11	10	9
Total Duration of Stops	0:13:25	0:11:30	0:11:54	0:10:03

Table 5 - Comparison between group A (n=75) and group B (n=75) regarding the mean and median values of the visit duration, total number of stops and total duration of stops.

Three nonparametric ANCOVAs were run to determine the effect of AR on each of the three variables, controlling for participants' previous visits to the Museum and to the Bone Hall. After adjusting the two covariates there was a significant difference in the total number of stops between group A and group B, $F(1,145)=4.702$ $p=0.032$. The difference in the visit duration and in the total duration of stops is not significant, $F(1,145)=2.041$ $p=0.155$ and $F(1,145)=0.222$ $p=0.638$, respectively. Therefore, when content is delivered in an augmented fashion visitors engage further with the exhibition by significantly stopping more often; they also linger more but without statistical significance when compared to those with no access to the technology.

Additional indicators of interest and engagement with the exhibition are some of the behaviors recorded during observation and tracking of study participants, namely "talks about exhibition," "calling others over," "takes picture" and "reads labels/text panels".

Figure 19 presents the distribution of behaviors by all of the stopping points and reveals that only talking about the exhibition and reading the textual content inside the display cases were prevalent. Participants did not often call other members of their party when the group was separated across the Bone Hall, and neither did they pull out their cameras or mobile devices to take pictures of the specimens while using Skin & Bones, even if these behaviors were observed during the baseline study and the pilot study, and thus included in the research protocol. Being part of the Museum study may have affected participants to some extent, focusing them on the task of testing Skin & Bones and dampening other typical behaviors. Additionally, handling the research iPad in a large, protective case may have made it cumbersome to reach for another device to take a picture, and participants may have been overly cautious protecting the iPad.

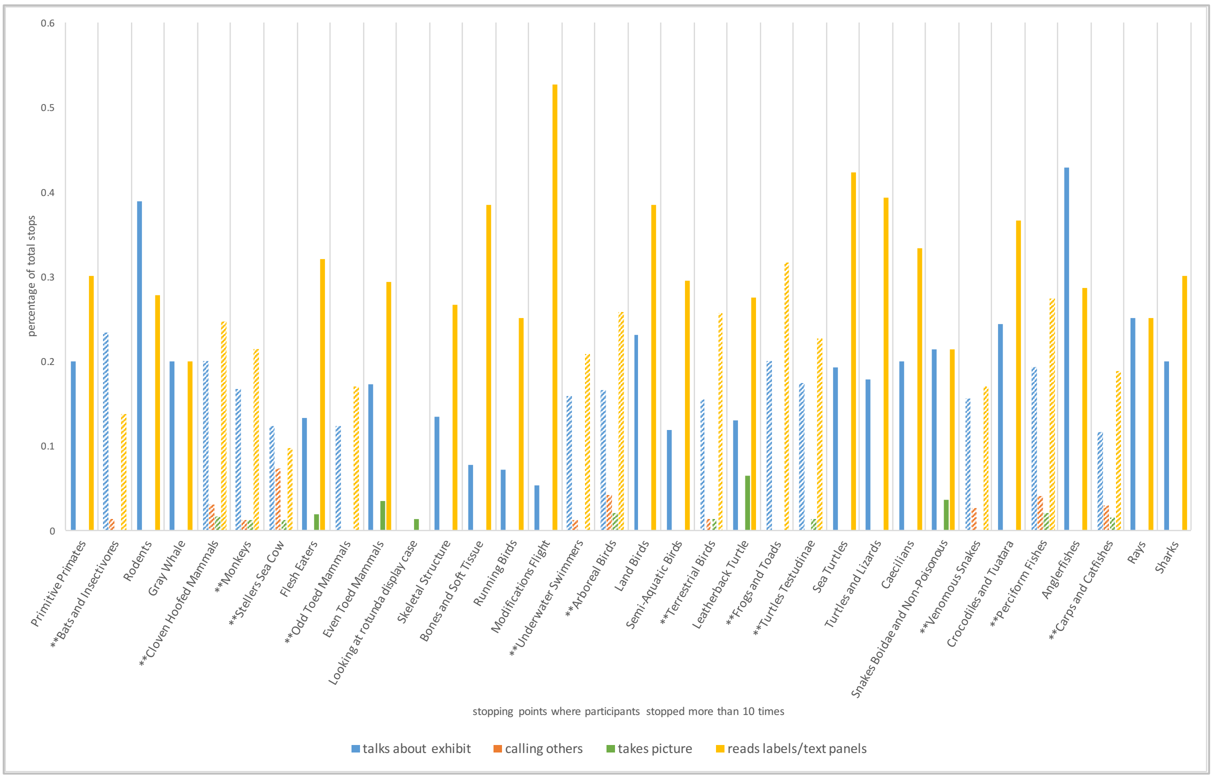

Figure 19 – Distribution of the percentage of total of stops where any of the behaviors occurred (blue "talks about exhibition", orange "calling others", green "takes picture", yellow "reads labels/text panels"), at stopping points where participants stopped more than 10 times. Double asterisk and patterned bars indicate a stopping point with Skin & Bones content.

To compare participants' behaviors in group A and group B as indicators of interest and engagement, only "talks about exhibition" and "reads labels/text panels" were used. It was hypothesized that participants that used Skin & Bones with AR technology talked more about the exhibition as an indicator of greater interest. With respect to reading the text inside the cases, there was no *a priori* hypothesis. On the one hand the technology-mediated experience could increase visitors' interest for learning more and reading specimen labels where they are available. On the other hand, the technology could draw the visitors' attention away from the specimen on display and exclusively on the digital content relegating the text to a lesser interest. For context, the design of the exhibition places text labels that are descriptive central to each case. The labels describe groups of specimens and not individuals, so a specimen included in the mobile app is unlikely to have any label description in the display case. Visitors would be reading the central display case labels.

The results showed that the two groups are not noticeably different (Figure 20) which was confirmed by the Mann-Whitney U tests. Median values of "talks about exhibition" and "reads labels/text panels" for participants who saw AR (1.87 and 1.88) and participants who saw AR-equivalent content (1.65 and 2.85), are not significantly different – U=2,699 z=-0.468 p=0.640 and U=5,925.5 z=1.075 p=0.282, respectively. Thus, seeing the augmented skeletons did not significantly lead participants to discuss differently the exhibition elements or to read the text panels.

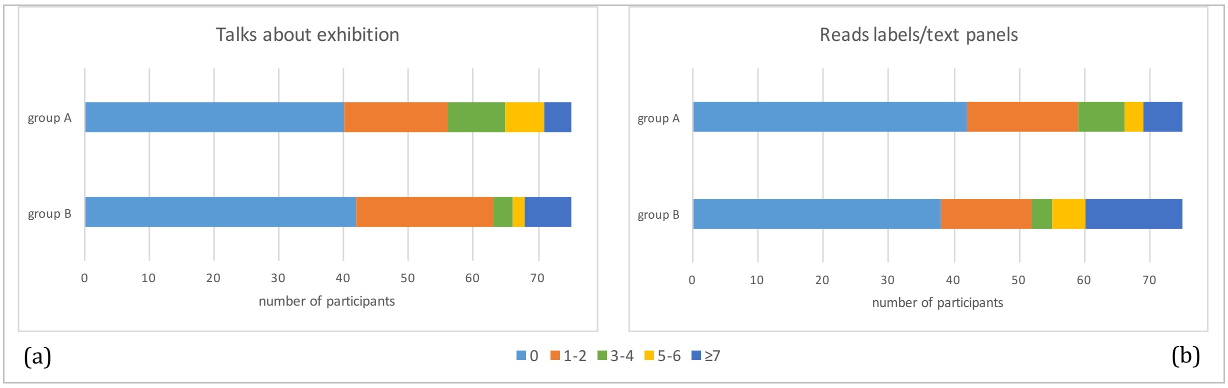

Figure 20 - Comparison between group A (n=75) and group B (n=75) regarding (a) the frequency of behavior "talk about exhibition", and (b) behavior "reads labels/text panels". Light blue represents no occurrences of behavior, orange 1-2 occurrences, green 3-4 occurrences, yellow 5-6 occurrences, and dark blue more than 7 occurrences.

These results may derive from an actual absence of influence of the AR technology over visitors' behaviors but may also be an artifact of the methodology and features inherent to the Bone Hall. Behavior "talks about exhibition" was recorded indirectly by observations of visitors pointing or gesticulating in front of the specimen cases and not by audio recording participants' conversations. This measurement may have under-reported visitors talking about the exhibition in cases where participants were in fact examining the skeletons and talking about their anatomical stories, but did not happen to physically gesticulate in ways that tied their conversation to the display case. In addition, the complexity of the scholarly terminology in the text panels may have acted as a deterrent to participants who otherwise would have enjoyed the extra source of content.

2.2. CONTENT VIEWING AND PREFERENCES

- Content Viewing

Skin & Bones has an abundance of wide-ranging content material, which gives users plenty of choices. There are 46 different pieces that users can choose from – 10 AR experiences, 32 videos and four activities – and dimensions – 1) stories about the roles the animals play in the environment (Animal Life), 2) human-interest stories exposing scientists' personal and formative experiences (Meet the Scientist), 3) particularities of the functional anatomy of the skeletons (Skeleton Works), 4) higher level scientific concepts that make connections across different species or discuss common ecological solutions (Big Idea), and 5) haptic interactions with the mobile device to enable physical experiences (Activities).

The pieces of content that participants in the in-exhibition-mobile-app study selected to view during their use of the app and the duration they saw them for were considered important indicators of the Visitor Experience. Participants with access to content in its augmented form were expected to view more of it and for longer than participants that had the equivalent non-AR images and animations in the app; they were also expected to favor AR experiences over videos and activities.

To compare groups A and B for their content engagement, two general measures were used: 1) the number of unique pieces of each type of content selected and 2) the duration they were viewed. Table 6 (p.100) includes the mean and median values of the number and duration of AR and AR-equivalent viewing (Skeleton Works menu option), video viewing (Animal Life, Meet the Scientist and Big Idea menu options) and activities playing. The table also includes the total content consumption and the results of the Mann-Whitney U tests.

Groups A and B proved to be significantly different in the number and duration of Skeleton Works pieces seen. Participants who had access to Skin & Bones content as 3D models and 3D animations superimposed onto the skeletons in the Bone Hall viewed it significantly more and for longer than participants who saw the static images and animations on the iPad screen without any interaction with the surrounding specimens. In fact, the average order of magnitude was seeing 6 times longer the static content and 2.8 times longer the animated content, revealing how AR technology extended participants' engagement with content in the exhibition.

Access to AR also had a replacing effect over the content format viewed. When the technology was available and participants encountered it, they significantly saw less of the alternate formats. In particular, they watched a smaller number and shorter duration of videos, and only viewed to completion a fraction of them, when compared to participants who had AR-equivalent in Skin & Bones. As a matter of fact, this was recorded for all video menu choices. Group A clearly chose AR over seeing Animal Life, Meet the Scientist or Big Idea videos. The replacing effect of AR over activities is not as significant as over videos likely due to the difference in the number of pieces available of each format– Skin & Bones has 32 videos and only four activities.

- Content Preferences

Equally relevant in the exploration of content is whether AR influences participants' stated preferences regarding their favorite animal in the Bone Hall exhibition and their favorite section in Skin & Bones. It was expected AR could influence favorite preferences to the extent that participants would declare that they liked best the animals that are augmented and the content area that offers the technology (Skeleton Works).

	group A		group B		Mann-Whitney U
	Mean	Median	Mean	Median	
Number of Skeleton Works pieces	4	4	2	2	U=1,496.5 z=-5.011 **p<0.0005**
Duration of Skeleton Works (static) pieces	0:01:18	0:01:08	0:00:13	0:00:08	U=793.5 z=-7.630 **p<0.0005**
Duration of Skeleton Works (animated) pieces	0:01:55	0:01:54	0:00:41	0:00:18	U=1,344 z=-5.577 **p<0.0005**
Number of Animal Life Videos	2	1	3	2	U=3,701.5 z=3.392 **p=0.001**
Duration of Animal Life Videos	0:02:40	0:01:19	0:04:18	0:02:30	U=3,602 z=2.976 **p=0.003**
Number of Meet the Scientist Videos	1	0	1	1	U=3,409.5 z=2.522 **p=0.012**
Duration of Meet the Scientist Videos	0:00:52	0:00:00	0:01:02	0:00:04	U=3,396 z=2.445 **p=0.014**
Number of Big Idea Videos[7]	1	0	1	1	U=2,237 z=1.716 p=0.086
Duration of Big Idea Videos	0:01:18	0:00:00	0:01:32	0:00:28	U=3,305 z=1.973 **p=0.048**
Total Number of Videos	4	2	6	4	U=3,742.5 z=3.515 **p<0.0005**
Number of Videos Completed	2	0	3	2	U=3,405.5 z=2.336 **p=0.019**
Total Duration of Videos	0:04:50	0:01:51	0:06:53	0:04:40	U=3,645 z=3.132 **p=0.002**
Number of Activities	0	0	1	0	U=2,998.5 z=0.827 p=0.408
Duration of Activities	0:00:21	00:00:00	0:00:22	0:00:00	U=2,929.5 z=0.518 p=0.605
Total Pieces of Content	9	8	9	7	U=2,631 z=-0.682 p=0.495
Total Duration of Content	0:09:33	0:07:06	0:09:08	0:06:08	U=2,653 z=-0.600 p=0.549

Table 6 - Comparison between group A (n=75) and group B (n=75) regarding the mean and median values of different measures of content viewing. Includes the results of the Mann-Whitney U tests with significant differences highlighted in bold.

[7] Viewing data of two content pieces from the Big Idea menu option were removed from the dataset in this analysis and all of the later analyses. The two pieces – American Bison Big Idea and Swordfish Big Idea – begin with an introduction video and are followed by an AR experience, unlike the other AR experiences that include no video. Participants were confused about how to activate the augmented content and many did not succeed, as discussed later (p.139).

The answers to the questionnaire regarding the favorite animal in the exhibition, and the first and second favorite section in Skin & Bones, are summarized in Figure 21 and Figure 22 respectively, showing how group A and group B vary in their preferences.

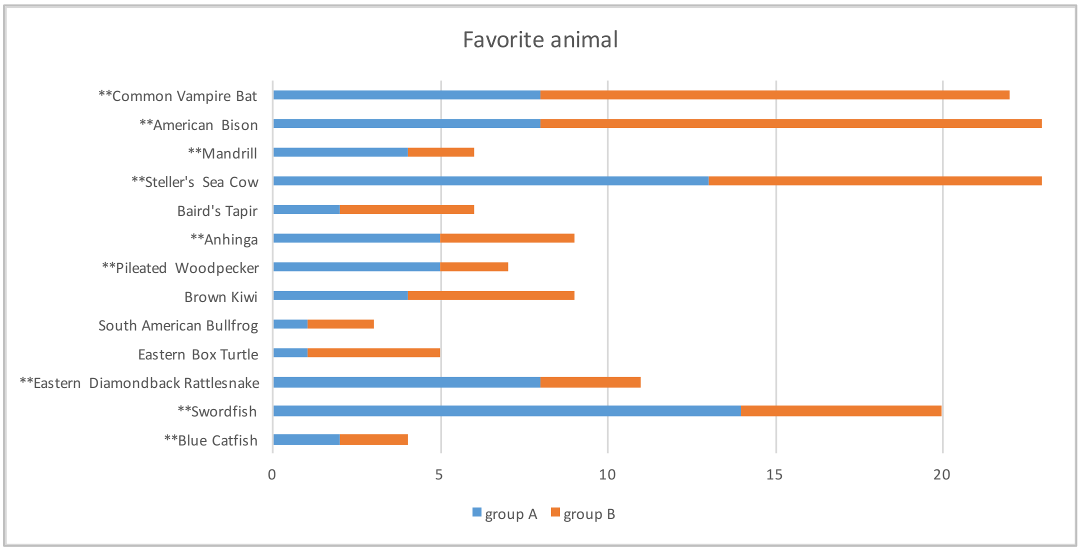

Figure 21 - Comparison between group A (blue) and group B (orange) regarding the favorite animal in Skin & Bones (group A n=75, group B n=73). Double asterisk represents animals with AR content.

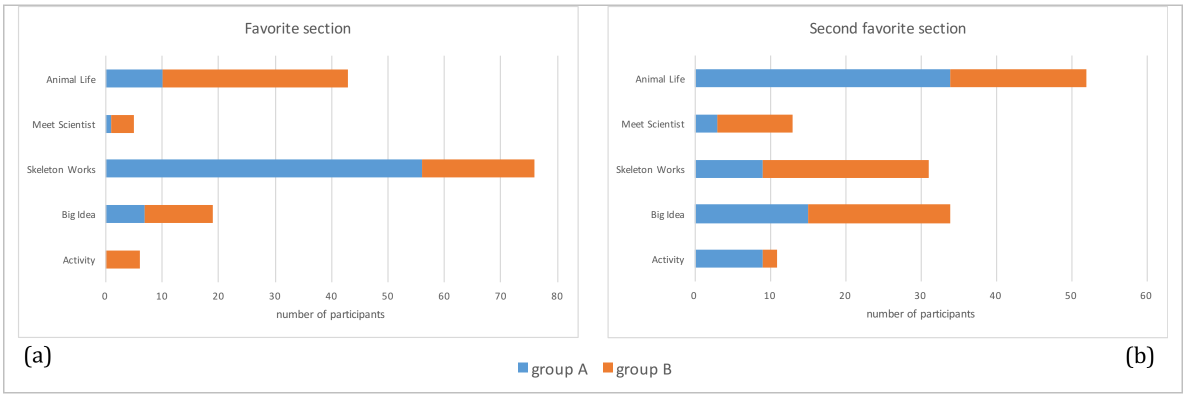

Figure 22 - Comparison between group A (blue) and group B (orange) regarding (a) the favorite section in Skin & Bones (group A n=74, group B n=75), and (b) the second most favorite section (group A n=70, group B n=71).

Figure 21 indicates that overall the American Bison and Steller's Sea Cow were the most selected animals, followed closely by the Common Vampire Bat and Swordfish. The least favored animal was the South American Bullfrog. These preferences are related to which of the 13 animals participants actually sampled. In fact, the question was "of the animals you saw in Skin & Bones, what was your favorite?" Plausibly, if visitors had not been to the display case or seen content in the app for the animal, they would not pick it as a favorite.

Differences between group A and group B are especially apparent when analyzing results concerning the selection of Skin & Bones animals with AR content (highlighted in Figure 21 with two asterisks). Animals associated with AR were significantly favored by participants who triggered the AR (Mann-Whitney U test: U=1,249 z=-3.007 p=0.003), whereas animals exclusively with video and activities content in the app were selected the most by participants who did not have access to the technology, even if without statistical significance (Mann-Whitney U test: U=67 z=0.473 p=0.681).

This influence of AR technology over group A's preferences prominently came across in the questionnaire open-ended question that asked for a justification of the animal selection. The quality of the augmented content and the experience of the technology were the most mentioned factors.

> (Steller's Sea Cow) *"The AR rendering was far better than expected and answered the question that I asked of what it looked like."*
>
> (Steller's Sea Cow) *"I had no idea what it would have looked* [like] *alive until I had the app – it was extinct but we actually got to see it."*
>
> (Eastern Diamondback Rattlesnake) *"It was very cool to see how the skeleton worked. I think more animals should have that feature when using the augmented reality option."*
>
> (American Bison) *"I loved the augmented reality breakdown that showed the family chain based on specialized ankle."*

The few justifications given by group A for the favorite animal picking that were not related to AR referred to the size of the skeletons, animal facts and pre-existing preferences.

> (Swordfish) *"Its bone structure was amazing, and very large."*
>
> (Blue Catfish) *"It was caught in 1879, weighed 150 pounds, and was shipped here. The history behind it was awesome."*
>
> (American Bison) *"Personal preference, it had little to do with the app."*

For group B participants that saw AR-equivalent content, the quality of its content execution, existing preferences and familiarity with an animal determined their selection.

> (American Bison) *"I learned about the special bone only shared by hoofed mammals like the bison. It wasn't just the same old same old behavioral info you can get watching* [the TV channel] *animal planet."*
>
> (Baird's Tapir) *"The narration here was particularly well done."*
>
> (Blue Catfish) *"Curator is awesome."*
>
> (Steller's Sea Cow) *"Read about it when I was a kid."*
>
> (Anhinga) *"I see them all the time where I live."*
>
> (Pileated Woodpecker) *"I am very familiar with these birds."*

Regarding preferences for Skin & Bones sections, Figure 22(a) shows that participants who saw AR strongly favored the Skeleton Works menu option, which is the app section that carries the augmented experiences. Participants who saw AR-equivalent content primarily favored Animal Life videos (Mann-Whitney U test: U=2,277 z=-2.062 p=0.039). This is similar to the analysis of content viewing preferences. AR had a replacement effect as group A participants named the Animal Life menu choice as their second favorite (Figure 22(b)). Thus seeing AR content pushes alternate options to a lower choice and markedly shapes visitors' preferences.

The open-ended answers of participants who saw AR and claimed Skeleton Works as their favorite section recurrently justified their selections with the contextualization of the graphics, motion and interaction with the skeletons.

> "[my favorite section in Skin & Bones was Skeleton Works because it is an] *innovative solution that's interactive and allows you to better understand the skeleton's influence on the animal's overall look.*"

> "*The augmented reality brought the bones to life and allowed me to see specifically where the bones are in the body.*"

> "*It was so cool to see the correlation between the skeleton and living organism. It contributed to those we saw but also gave context to the other skeletons*."

> "*I like that it was interactive and that it showed you how this animal would move. This was definitely the coolest part. I wish all the animals had had the skeleton works option!*"

> "*It is interesting to see the various bones working within the animal, or getting a general feeling of how a living equivalent would look like.*"

The few explanations from participants in group A that favored sections in Skin & Bones other than Skeleton Works related to preferences for content dimensions.

> (Meet the Scientist) "*It was fascinating to hear the stories that the scientists had to tell, especially about how certain activities in their youth pushed them into a career in science.*"

> (Big Idea) "*Liked learning about the overall concepts governing a species.*"

Group B chose the Animal Life section as the favorite content area and the AR-equivalent Skeleton Works as second favorite, and the reasons indicated by most related to the added information about the animals.

> "*Got to know more general information about the animals.*"

> "*I am interested in the biology and evolution of animals, and getting an in depth look at the build of animals through the app was very interesting.*"

> "*I liked how it introduced a unified concept of the animals on display or convergent evolution between different species, etc.*"

> "*Because it made me think about things.*"

In conclusion, delivering content in the exhibition through AR technology considerably promoted the viewing of more content and for longer periods of time when compared to a more traditional video format. The experience of the technology was so influential that the augmented objects in the exhibition and the app section delivering the AR experiences became visitors' favorites. The viewing of AR also had the effect of reducing the consumption of content in other formats.

2.3. VISITOR SATISFACTION AND MEETING OF EXPECTATIONS

Visitor satisfaction and meeting of prior expectations are addressed in the questionnaire by collecting participants' ratings of their satisfaction with the visit to the Bone Hall and experience with Skin & Bones. One question regarding the intention to download the app to a personal device after the visit was included as an additional indication of satisfaction. Participants that used the AR-version of Skin & Bones were expected to express higher levels of satisfaction and to affirm their expectations had been met when compared to participants that did not get to use the technology.

Figure 23 through Figure 25 illustrate the results of comparing group A and group B for the different satisfaction and expectation metrics. Overall the level of satisfaction was noticeably high to the great majority of participants. Both groups rated the visit and the app in the range of good to superior, and both indicated an intention to download Skin & Bones after their visit. They agreed that the visit to the Bone Hall was better than expected. However, when it comes to distinguishing the two groups, the data indicates that they are not greatly different, except for an apparent small trend of participants who saw AR who considered the visit and the app experiences superior over participants who saw AR-equivalent content. Also, group A declared an intent to download Skin & Bones more frequently than group B but said that the visit was as expected. Participants in group B said the visit was better than they expected slightly more than group A.

The median values of three of the four variables are the same for both groups – the experience at the Bone Hall was excellent; the experience with Skin & Bones was excellent; and they have no intention to download the app to their own devices. Regarding the meeting of expectations, the median value for group A was that the visit was as expected, and for group B it was better than expected. The Mann-Whitney U tests confirmed that there are no significant differences between the groups for each of the dependent variables – rating of the visit experience in the Bone Hall U=2,595 z=-0.918 p=0.359; rating of the experience with Skin & Bones U=2,473.5 z=-1.372 p=0.170; intention of downloading Skin & Bones U=3,109.5 z=1.856 p=0.063; and meeting of expectations U=2,855 z=0.176 p=0.860.

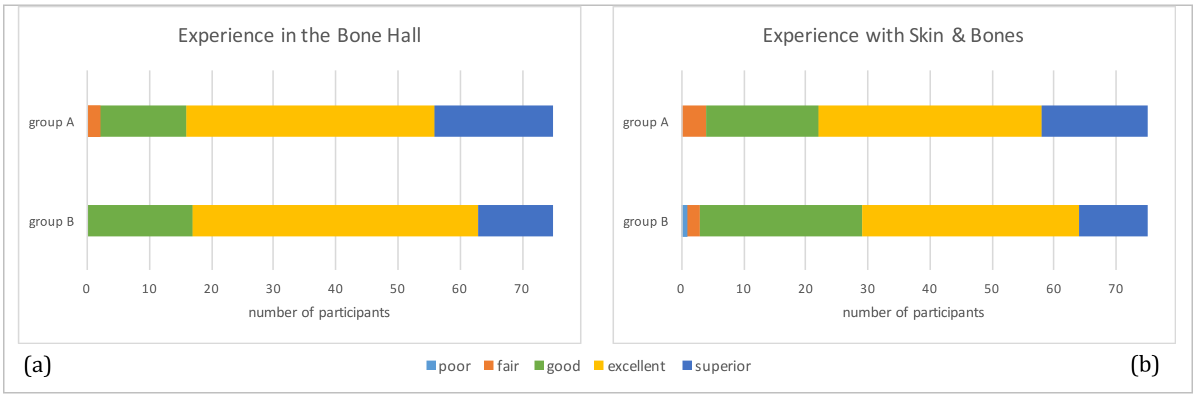

Figure 23 - Comparison between group A (n=75) and group B (n=75) regarding (a) the rating of the experience in the Bone Hall, and (b) the experience with Skin & Bones. Light blue represents participants with a poor experience, orange a fair experience, green a good experience, yellow an excellent experience, and dark blue a superior experience.

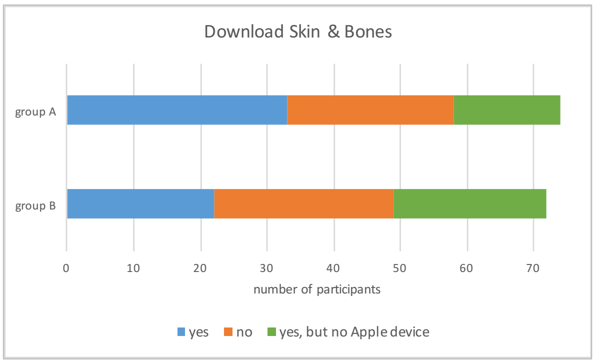

Figure 24 - Comparison between group A (n=75) and group B (n=72) regarding the intention to download Skin & Bones to a personal device. Light blue represents participants who answered yes, orange those who answered no, and green those who answered yes but do not own an Apple device.

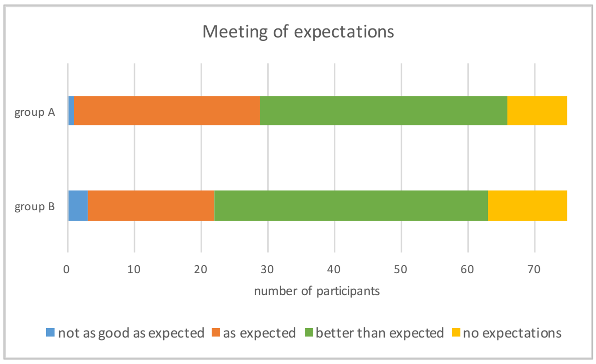

Figure 25 - Comparison between group A (n=75) and group B (n=75) regarding the meeting of expectations. Light blue represents participants with an experience not as good as expected, orange an experience as expected, green an experience better than expected, and yellow participants with no previous expectations.

Therefore, according to the questionnaire data and unlike what had been hypothesized, AR did not make a significant contribution to increase visitor satisfaction levels or in meeting prior visitor expectations.

The general considerably high satisfaction with the visit and the app may have interfered with the granularity needed to surface a potential effect of AR technology. Visitor studies at Smithsonian museums have revealed the appreciation by the general public of the cost-free and high quality offerings of the institution, and seldom are study participants very critical of their experiences. The well-known profile of the Museum visitors, described previously (p.52), may have equally interfered with the meeting of expectations results. Typically, individuals are well educated but non-specialists in natural history who arrive to the building without predetermined ideas of where to go and what to see, and seldom have formed strong expectations about particular exhibitions. In fact, the examination of the participant sample of the in-exhibition-mobile-app study revealed that the majority of participants were on a general visit to the Museum and happened upon the Bone Hall. They were not intentionally deciding to visit that exhibition. Many participants said they had no previous expectations or that the visit was as expected (Figure 25). That most participants had never experienced AR or a mobile app in a museum setting also indicates any thing like Skin & Bones would have aligned with their expectations. Thus, not just the satisfaction level results may have suffered from lack of granularity due to the circumstances of the case study, results regarding the meeting of expectations might have equally been affected.

Interestingly, the results of the multivariate analysis that analyzed all of the study variables provides complementing information to these findings and suggests that there are high levels of visitor satisfaction and meeting of expectations connected with AR technology, unlike what the analyses above revealed. Next the two stages of the multivariate analysis are described and the interpretation of the results are discussed.

- Multivariate Analysis

It was described previously (p.85) the reasoning and approach to a multivariate analysis of the in-exhibition-mobile-app study data. A CATPCA test was run with all of the study variables with the goal of reducing the large data set onto a smaller one that accounts for most of the variance.

The test revealed 12 components that had eigenvalues greater than one and which explained 17.7%, 9.6%, 8.4%, 5.5%, 4.7%, 4.5%, 4.1%, 4.0%, 3.7%, 3.2%, 3.0% and 2.9% of the total variance, respectively. Visual inspection of the scree plot indicated that four components should be retained. This four-component solution accounts for 50.6% of the total variance.

The variance accounted for by each component and the component loadings at every variable relate component 1 to the total viewing of content in Skin & Bones, both in number of pieces and duration watched, and with total viewing of videos. They further link component 2 with instrumental and emotional experiences, component 3 with viewing of Skeleton Works content, and component 4 with the participants' sociodemographic information and previous visits to the Museum and to the Bone Hall.

The four components were in turn used in a hierarchical cluster analysis to assemble the 199 participants into groups according to their similarities. After visual inspection of the dendrogram and after analysis of the clusters against the original variables, six clusters were retained. The table presented on Appendix C plots the six clusters against the original variables and informed the characterization of the clusters. Described below are the participants' features that stand out in each cluster, when compared to the participants in the other clusters.

- Cluster 1 – comprises the greater number of participants (n=58), mostly from around the U.S. and of Caucasian ethnicity, with bachelor or graduate/professional degrees, and with ages ranging from 21 to 50. Most had not been to the Museum or to the Bone Hall before. They are categorized in the IPOP framework as Idea, People and Object people. For the most part, they did not see AR during their visit to the exhibition, and they rated the experience at the Bone Hall and with Skin & Bones as "good" and "excellent". The visit was as they expected or they had no previous expectations. Mainly the participants stated not intending to download the app, or not being able to for not owning Apple devices. Their comfort level with technology ranges from "neither comfortable nor uncomfortable", to "somewhat comfortable", to "comfortable". The level of agreement with positively phrased statements that reflect different classes of experiences ranged from "neutral" to "agree" regarding Skin & Bones helping to connect with the exhibition, meeting their interest to know about the animals, being amazing to use or sparking an interest to know more. The level of agreement with the negatively voiced statements ranged widely from "disagree" to "agree" with not wanting to share the app with friends or the app not holding their attention. Their favorite sections in Skin & Bones were Big Idea and Animal Life. In total they saw a moderate amount of content, between 3 and 6 pieces, of which none, or 1 to 2, were Skeleton Works, and 3 to 6 were videos across all categories. Most participants did not play activities. The duration of content watched was overall low to medium.

The large number of participants mathematically assembled in this cluster, resulted in a heterogeneous group with a wide-range of characteristics. There is no strongly defining trait connecting their preferences or sociodemographic information with their use of the app and experiences in the exhibition.

- Cluster 2 – comprises 30 participants, that are the youngest among all clusters, with ages ranging from 10 to 20, and accordingly have education levels identified as "less than high school" and "high school". Most individuals are in the Physical dimension of the IPOP framework. They saw a medium amount of content pieces, between 7 to 10, which included mostly Skeleton Works and a low number of videos.

  This is a coherent group of participants that meets the typical stereotype of a young visitor to a natural history museum, with a penchant for physical activities. They do not commit to seeing a large amount of content and select the interactive experiences, favoring AR over video.

- Cluster 3 – comprises 35 participants that, when compared to the participants in the other clusters, saw the greatest amount of AR content. They are the most emphatic about their experience as indicated by "superior" ratings to the experience in the Bone Hall and Skin & Bones, stating that the visit was "better than expected", and indicating their intention to download the app to their own devices. They agreed and strongly agreed that the app made it easier to connect to the exhibition, that it met their interest to know about the animals, that it was amazing to use and that it made them want to discover more about the animals. They disagreed and strongly disagreed with the app not holding their attention, and somewhat disagreed with not wanting to share the app with friends. Their favorite section was Skeleton Works. They saw a high number of pieces of content, between 11 to 14, which included the most viewing and longest duration of Skeleton Works content. Their engagement with AR also correlates with the lowest viewing and duration of videos, when compared to the other clusters.

The choices and experiences of the participants gathered in this cluster are the most revealing of this research study. In a very explicit and unambiguous way they demonstrated that higher viewing of augmented content is associated with greater satisfaction and meeting of expectations. This cluster clearly preferred content delivered through AR technology. Overall the Visitor Experience of these participants was very positive, which led to seeing a greater than average number of content pieces and for longer durations. The effect of content type displacement that previous data analyses indicated is apparent here again as the higher consumption of AR content greatly diminished the viewing of video.

- Cluster 4 – comprises 32 participants, the ones that had been to the Museum and the Bone Hall previously, when compared to participants in other clusters. They feel somewhat uncomfortable with technology and rated the experience with Skin & Bones as “fair”. Across all classes of experience, they mostly had less positive experiences, disagreeing at different levels or being neutral about the app making it easier for them to connect to the exhibition, meeting their interest for knowing about the animals or being amazing to use the app. They somewhat agreed that it did not hold their attention and they did not want to share it with their friends. As expected from the responses of this cluster, they saw low numbers and short durations of pieces of content.

  For this group of participants that admittedly felt somewhat uncomfortable with technology, using Skin & Bones was fairly dissatisfying and overall the experience of the visit was not positive. They reflect the concerns raised by some museum professionals regarding the introduction of technology to exhibitions directing attention away from or even interfering with the experience of visitors that are not digitally-inclined. Nevertheless, these are the participants that had they not been asked to be part of the Skin & Bones study, would have chosen to visit the Bone Hall in its analog condition and perhaps would have been more satisfied with the experience.

- Cluster 5 – comprises the smallest number of participants (n=17) that are set apart from participants in other clusters for having seen the highest number of pieces of content in Skin & Bones, including Skeleton Works pieces, videos and activities.

  The small dimension of this group of participants that viewed the most content in the app, of all types, is consistent with museum studies literature that shows that only a reduced subset of visitors is interested in lingering in the exhibitions to absorb what they can for an extended period of time.

- Cluster 6 – comprises 27 participants and it is the cluster with more participants in the age range of 61 to 70. They saw a medium amount of pieces of content, mostly Animal Life videos, yet for longer than participants in other clusters. Coherently, the majority of participants in this cluster identified Animal Life as their favorite section in the app.

  Similarly to cluster 2 that mirrors the typical stereotype of a young visitor in a museum exhibition, this group of participants fits the profile of senior visitors. Their preference is for a traditional content format, video, and traditional content style, short animal documentaries. They reveal their preferences and possibly their increased attention spans by watching the videos for longer than other participants.

With the exception of cluster 1 which is too generalist to provide insights into profiling the experience of visitors using AR technology in a museum exhibition, all other mathematically assembled groups of participants are consistent with existing knowledge and reveal interesting connections between consumption of different content formats, including AR, different types of content, amount of content viewed and visitors' age.

When analyzing all study variables, it is possible to isolate participants who saw the augmented content from those who saw the equivalent non-augmented content for participant satisfaction and meeting of expectations. The homogeneous group that stands out is the group of participants who saw the greatest amount of augmented content (cluster 3). This group is associated with greater satisfaction – "superior" ratings of the experience in the Bone Hall and Skin & Bones, and declared intention of downloading the app – and the group indicated their expectations had been surpassed. Thus, the multidimensional study of the Visitor Experience strongly supports the positive influence of AR technology over visitor satisfaction and meeting of expectations, two critical aspects of the Visitor Experience.

2.4. USER EXPERIENCE

Aiming to examine the Visitor Experience with AR technology in museum exhibitions, this research surveyed existing frameworks in the UX field that could be adapted for this study and complement the other more traditional museum research methods used. The survey led to the adoption of a framework developed particularly for evaluating the UX with mobile AR services that categorizes experiences in six upper level categories, each with a specific metric, which was modified for the case study.

Groups A and B were again compared to evaluate similarities and differences in their experiences across each of the six categories defined by the framework: instrumental, cognitive and epistemic, emotional, sensory, social, and motivational and behavioral. Participants rated their experiences by selecting one in seven Likert items that expressed the level of agreement with six statements, one for each category.

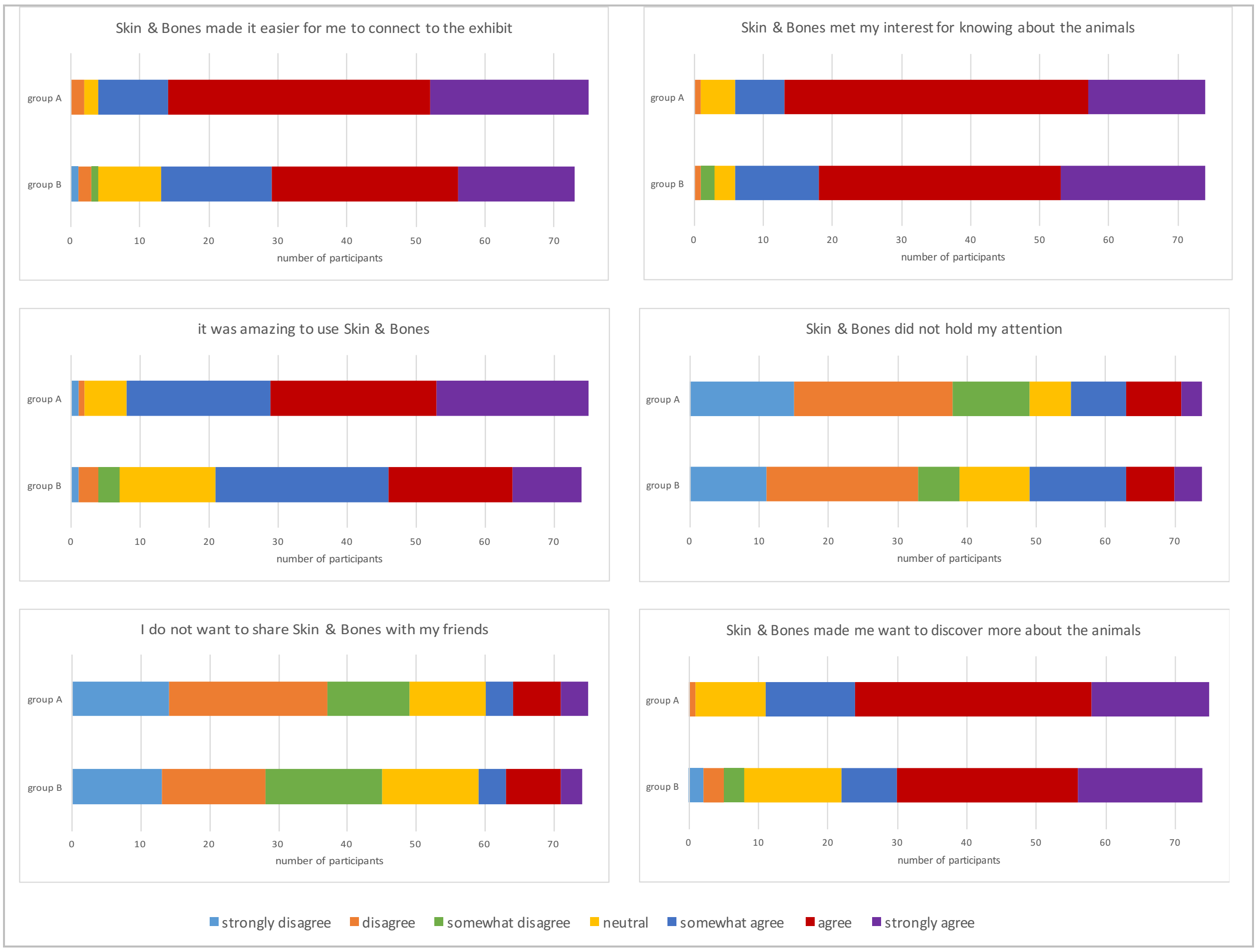

Figure 26 - Comparison between group A and group B regarding each of the six statements that rates the Visitor Experience with AR. Light blue represents participants that strongly disagreed with the statement, orange that disagreed, green that somewhat disagreed, yellow that were neutral, dark blue that somewhat agreed, red that agreed, and purple that strongly agreed.

AR technology was expected to increase the different types of experience, facilitating the connection with the exhibition, fostering emotions, developing learning opportunities, absorbing participants' attention, encouraging social relations and sparking curiosity about the specimens.

As Figure 26 illustrates, there was an overall trend of agreeing to the statements phrased with a positive voice and disagreeing to the statements phrased with a negative voice, indicating a largely positive experience in all six categories.

Participants that saw AR content and participants that saw AR-equivalent content are mostly set apart in experiences of instrumental nature ("Skin & Bones made it easier for me to connect to the exhibition") and in emotional experiences ("it was amazing to use Skin & Bones"), with the first group largely agreeing more with the statements. A Mann-Whitney U test confirmed the differences – "Skin & Bones made it easier for me to connect to the exhibition" U=2,145.5 z=-2.407 p=0.016; "it was amazing to use Skin & Bones" U=1,921 z=-3.350 p=0.001.

As far as the other categories of experience – cognitive and epistemic ("Skin & Bones met my interest for knowing about the animals"), sensory ("Skin & Bones did not hold my attention"), social ("I do not want to share Skin & Bones with my friends") and motivational and behavioral ("Skin & Bones made me want to discover more about the animals") – differences are not as apparent, even though in general, group A tended to agree more with the positive voice statement related to motivational experiences, and disagree more with the negative voice statements related to sensory and social experiences. The Mann-Whitney U tests revealed no significant differences between the two groups – "Skin & Bones met my interest for knowing about the animals" U=2,727.5 z=-0.044 p=0.965; "Skin & Bones did not hold my attention" U=3,031.5 z=1.149 p=0.250; "I do not want to share Skin & Bones with my friends" U=2,974.5 z=0.771 p=0.440; "Skin & Bones made me want to discover more about the animals" U=2,491.5 z=-1.125 p=0.260.

Participant perceptions collected during the interviews supported these findings. Instrumental experiences were exposed through feelings of connectedness, meaningfulness and the relevancy of engaging with the augmented content.

> "(…) *I think it had a lot more layers and understanding*."

> "*If you're looking at something that makes you think about how it operates, or think deeper about what you're seeing, you're engaged in a way that you aren't if you just sort of…"*

Participants mentioned they related better to the exhibition due to the addition of interaction and motion, granted by the uniqueness of the augmented technology. AR played a facilitator role in those visitors' experience. They admired the responsiveness of the 3D tracking[8].

> "*It's good that you can follow it around, that it's not just stationary. And it's got, when you turn it on the skeleton, it actually changes the position where it's looking at you*".

They also appreciated the movement of the superimposed content and favored the augmented animations over the static skinning of the skeletons.

> "*It appears like a physical element, like the bat that's moving, the monkey that's there. And you're holding the thing as well, moving about. It engages different areas of your person*."

> *"The thing that I loved about it was the Skeleton* [Works menu option]*, where you can pull up the Skeleton and see the interactive ones; the Bat and the... what was the other one that moved? Oh, the Rattlesnake, where you can see it unhinging its jaw and stuff like that, that's really cool. It kind of made just holding it up and seeing the* [static] *fish, kind of boring* [chuckles]*."*

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[8] The appreciation of the 3D tracking feature in AR is interesting in the context of the Bone Hall, considering the limitation of the displays – the skeletons are not free standing and instead are contained in glass cases, thus not affording 360º superimposition. Nevertheless, the limited range of motion was enough to appeal to participants. One study has shown that visitors not always understand that they can move around an object and augment it 360º (C. B. Madsen et al., 2012).

In an otherwise entirely static and non-interactive exhibition, such response is to be expected, despite the augmentation. In fact, participants who used the non-AR-version of the app, also commented positively on the videos.

> "(…) *it's interesting to be able to watch videos on these animals that I know nothing about and learn a little bit, even if they're only 2 minute videos they've got good information in them*."

However, the results revealed the particular interest among visitors who saw the images and animations superimposed onto the skeletons, rather than uncoupled from the physical environment. It can be argued that experiencing content was further heightened by the real-time registration, which brought about a greater focus and engagement. This especially came across in the comments related to the functional anatomy of the animals, which were overwhelmingly consistent in describing the relationship between the digital and physical.

> "*You could see the skeleton there and then to see the actual anatomy and physiology of the animal working while it's unhinging its jaw, the muscles are releasing the venom into the prey, just kind of be able to take one of these skeletons and visualize how it works when the animal is alive. It's neat*."

Developing exhibition content that shows "how things work" is not a new strategy in museums, but through AR technology it gained relevance due to the contextualization and visual impact, and made a significant difference in facilitating visitor appreciation of the specimens on display.

Besides having instrumental experiences of connectedness and relevance when engaging with the augmented content, participants who saw AR agreed, to a significant degree, with having had emotional experiences. In the questionnaire they stated more frequently that Skin & Bones was amazing to use, and perceptions from the interviews exposed feelings of wonder and surprise.

> *"(…) The big ones like the manatee* [Steller's Sea Cow] *you can step back and see 'wow, that's what it looks like'."*

> *"That's the first time I've ever seen anything like that before, which is sick, so…"*

> "*Holding this up and seeing stuff is kind of a new thing for me*."

These reactions were predictable and are understandable, considering that the vast majority of visitors had never experienced AR or even used a mobile app in a museum before. For the visitors this was such a novel way of going about an exhibition, and this type of experience was the most articulated and reflects the importance of stimulating emotional reactions of pleasure, entertainment and wonder in museum exhibitions.

The other categories of experience – cognitive and epistemic, motivational and behavioral, sensory and social – were more pronounced among participants who used the AR-version of the app but not to the extent of yielding significant differences to those who did not view augmented content.

Participants were asked about their agreement level with Skin & Bones meeting their interest for knowing about the animals (cognitive experience). Even though the results did not demonstrate that AR significantly promotes this type experience, the interview data revealed repeated mentions of "learning," "understanding" and "engagement." Some participants in fact stated that learning with AR was an improved form of learning.

> "*(...) having this would really help me to learn the information that I got.*"

> "*You can learn something, but it's not like 'oh, I have to learn something'.*"

Also, participants linked the cognitive aspect of their experience to multisensory stimulation, facilitated by the augmented motion and interaction.

> "*And you see and hear about nature, about the woodpecker pecking, and think about how the woodpecker manages to do that. It's interesting. I'm a visual learner, so to be able to hear it and then also see it, I think it had a lot more layers and understanding.*"

Traditionally, visitors expect to have a learning experience when they go to a museum. Inevitably they associate museums with visits by school groups, either those they participated in as students, or the ones that are taking place at the same time they are visiting. Therefore, it is expected that they employ vocabulary that includes learning as an outcome of the visit. In retrospect, rephrasing the questionnaire statement from "Skin & Bones met my interest for knowing about the animals" to "Skin & Bones helped me learn about the animals" might have been a more direct approach to assess the influence of AR technology over the development of cognitive experiences. Nevertheless, despite participants' statements and the establishment that museums are primarily institutions that serve an educational mission, learning as a single outcome or the most important goal has been demoted in favor of promoting connections between visitors and themes that are personally relevant to them, as discussed in the literature review. Consequently, even if AR technology is more capable at elevating instrumental experiences over cognitive ones, its contribution to a museum exhibition is still of relevance.

The questionnaire results additionally show that AR does not foster motivational and behavioral experiences. Participants who saw AR did not significantly want to discover more about the animals than participants who saw AR-equivalent content. This outcome arguably may be attributed to the nature of the content of the app more than to the technology. Skin & Bones was not designed with particular calls to action, users were not directly prompted to explore further about the animals and did not feel compelled to do so. In fact, as discussed in the literature review, museum exhibitions in general have been found to be somewhat deficient in promoting attitude change.

The statement "Skin & Bones made me want to discover more about the animals" was phrased to reflect "inspiration" and "motivation" that the author of the adapted framework, Olsson, lists under the umbrella category motivational experiences. However, "creativity" is also under that category, and in the author's words "*creativity represents self-expressive and artistic feelings in users creating AR content and in mixing the digital with the real world in previously unimaginable ways.*" (Olsson, 2013, p.217). Mobile augmented tools developed in museums to promote visitor-generated content (such as the augmented coloring activities at the American Museum of Natural History or at the National Museum of Nature and Science in Tokyo) would be expected to promote the creative aspect of motivational experiences in a unique way and perhaps reveal significant contributions of the technology.

Another experience category investigated that did not yield significant differences was sensorial experiences. Participants who used AR did not state having their attention held by Skin & Bones to a greater significant degree than participants without access to the technology. Yet considering how Olsson describes "captivation" within the umbrella category sensory experiences – "*the feeling of being immersed and engaged in the interaction with the environment enriched with AR content*" (p.215) – there is the realization that such experiences were much developed among participants who saw AR. In the perceptions captured by the interviews, the detail with which some participants described what they had experienced was common and indicative of the rapture and engagement with the augmented content.

> "(…) *you think about bats flying and sure you'll see them fly past you, and it's 'ugh, it's a bat'; and then to think about that they also feed on humans, it's interesting; instead of just walking by and be like "look, it's a bunch of bats", it's a specific bat doing all that weird stuff. When you see the teeth, you don't think about it, but then they go into specifics talking about what it is that the teeth do, to puncture the animal's leg; it talked about the bat community and how younger bats sometimes nurse in females and don't always get to go out and hunt, so the community comes and supports each other, I thought that was interesting."*

> "*You could see the skeleton there and then to see the actual anatomy and physiology of the animal working while it's unhinging its jaw, the muscles are releasing the venom into the prey, just kind of be able to take one of these skeletons and visualize how it works when the animal is alive. It's neat.*"

In addition, had participants' attention not been held, those who used the AR-version of Skin & Bones would not have significantly seen more augmented content or stopped more often in the Bone Hall than those who used the non-AR-version. These can be considered sound indicators that participants had sensory experiences when exposed to AR technology.

Regarding the last category, social experiences, once again participants who used the technology did not agree to a significant degree with wanting to share Skin & Bones with their friends. Despite one participant's comment about the app being a good resource to show family and friends the exhibition, most participants did not refer to the app as playing a social role. Two factors possibly contributed to this result. First, similarly to what has been argued about motivational experiences, Skin & Bones was not specifically designed to foster collective interactions or social sharing. Unlike some of the AR apps examined in the literature review that facilitate multi-user augmented activities (such as those developed by the British Museum), Skin & Bones is mostly an individual tool. Even if it can be shared by a small group of visitors in the sense that a few individuals can watch the display simultaneously, it does not intentionally encourage social connections within the group. Second, participants encountered difficult audio problems as a consequence of the crowds creating a lot of noise in the Bone Hall and repeatedly mentioned the necessity to wear a headset[9]. This likely contributed to the impression that Skin & Bones is not a shareable tool within the exhibition and beyond it.

> "*I don't know if two people can really use it, because if you have headphones it's mainly one*."

Nonetheless, one social outcome remarked as positive and unexpected by the study's participants, was the interaction generated between unrelated visitors. These interactions were prompted by individuals who were not study participants yet observed study participants using the app and seeing the AR experiences.

> "*We definitely found ourselves using the augmented reality stuff the most, and like a small crowd of children would gather around and check out.*"

> "*Just when we were over there, looking at that Swordfish, a couple of kids came up to us 'wow, is that an app?' 'that's so cool!'. They pulled out their phone right away and see if they could download the app*."

In conclusion, the results of the analyses of the different categories of experience considered only partially met the initial expectation that AR technology has a significant and positive influence over all of them. It is important to note that analogous to the participant satisfaction and meeting of expectations data, the results of the multivariate analysis give a different depiction. The group of participants who saw the greatest amount of augmented content (cluster 3) not only agreed and strongly agreed that Skin & Bones made it easier for them to connect to the exhibition, that it met their interest to know about the animals, that it was amazing to use and that it made them want to discover more about the animals, but they also disagreed and strongly disagreed with the app not holding their attention. They were less assertive regarding social experiences, only somewhat disagreeing with not wanting to share the app with friends. Thus, the multidimensional study of the Visitor Experience supports strongly the positive influence of AR over five categories of user experience (instrumental, cognitive and epistemic, emotional, motivational and behavioral, and sensorial) and to a lesser extent but still positively the development of social experiences.

[9] This subject will be developed further later (p.145).

3. DIGITALLY ENHANCED ANTIQUATED EXHIBITIONS

In addition to studying the Visitor Experience with mobile AR, this research looks at the effects of digitally enhancing antiquated museum spaces that remain physically unchanged for decades. For research purposes the question is "how does the digital enhancement of antiquated museum exhibitions affect the visit and the visitor?"

Based on casual observations and later, a baseline study, it was hypothesized that these outdated displays do not meet visitors' interest, and that the individuals whose visit is mediated through mobile technology are affected positively. In order to test the premise, data was collected both during the baseline study when there was no technology available in the exhibition, including Wi-Fi, and with the mobile app Skin & Bones during the in-exhibition-mobile-app study. In the first, participants were visiting the Bone Hall as they would other exhibition in the Museum without a mobile app, and in the second they were carrying an iPad with Skin & Bones. Data from the in-exhibition-mobile-app study was analyzed altogether, i.e., collected directly from the iPads used by visitors to explore the Bone Hall with whichever version of the app they received, either the AR-version or the non-AR-version.

Specific differences in the pattern of visitation were investigated between participants that were observed and tracked before and after the introduction of the app. The perceptions of participant interviews (after using Skin & Bones) were also analyzed to identify insights regarding the Bone Hall as an aged museum space, and make comparisons between the experience of visiting the exhibition with the app and visiting another museum exhibition without digital enhancement.

3.1. PATTERN OF VISITATION

Data relating to the pattern of visitation was explored in an analogous way to the comparison between group A and group B described previously, except the comparison was done with observation and tracking data of participants visiting with and without Skin & Bones, using records of their visit duration, number of stops, duration of stops and visit path.

Participants of the baseline study were notable for the short duration of visits, an average of 0:03:24. However, the mode of this metric was 0:01:34 and that better reflects the brief extent of the stay, since only 26% of participants lingered longer than 0:03:00. Contrastingly, when using Skin & Bones participants had visits averaging 0:14:00, with most lasting between six to 20 minutes, as seen in Figure 27. The overall duration of the visit was then dramatically influenced by the introduction of the app, increasing fourfold.

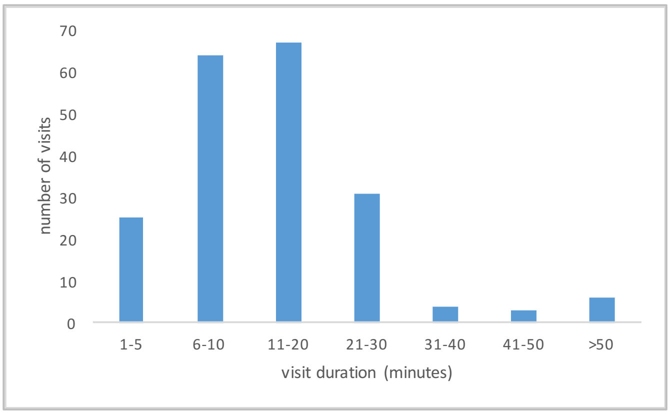


Figure 27 - Distribution of the number of visits (N=199) according to the visit duration.

The fleeting character of the visit in the absence of a digital tool is echoed in the number of stops. Out of the 128 visitors observed and tracked during the baseline study, only 85 (66.4%) stopped in front of at least one display case during their path along the Bone Hall; the others used it exclusively as a passageway to get to other parts of the Museum. Their average number of stops is 5 and mode 1. In fact, 28% of participants only stopped once, and 64.7% stopped 5 times or less. Even considering the Museum where the studies were taking place and the profile of its visitors – i.e., a large building with free of charge admission visited mostly by tourists with limited time and a busy agenda – the passing visits to the Bone Hall made it rank low as a destination inside the Museum.

While using Skin & Bones participants stopped in the Bone Hall as little as once and as many as 42 times (Figure 28), in average twice as much as visitors browsing the exhibition without the app. Whereas individuals observed during the baseline study only stopped at a small fraction of the stopping points, participants tracked after the digital enhancement stopped on average at 19% of those points.

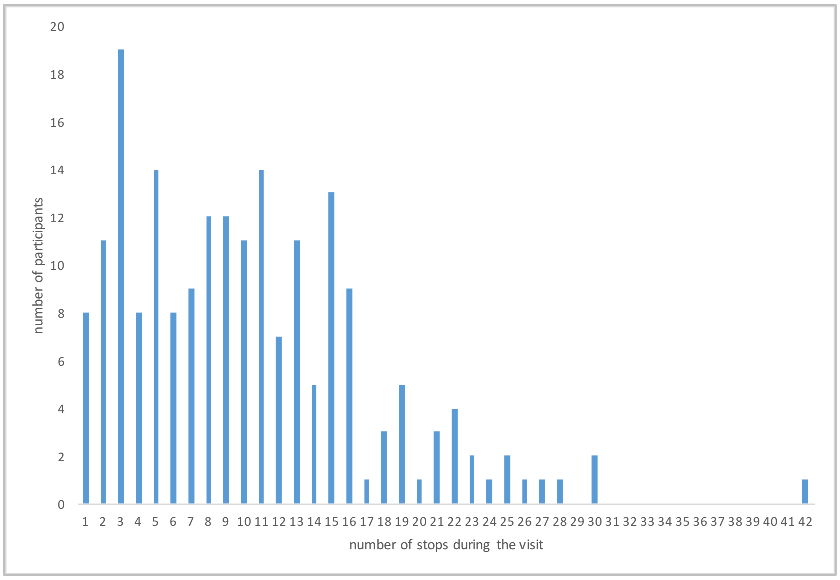


Figure 28 - Distribution of participants (N=199) according to the number of stops during the visit.

A 19% rate of stopping by display cases is similar to what was recorded in a study done at a different gallery in the Museum, the Kenneth E. Behring Family Hall of Mammals (Munteanu & Pekarik, 2005). This exhibition opened in 2005 and was designed from the ground up to replace the previous mammal hall that was removed in its entirety. It features an extensive number of taxidermied animals, some of large dimensions similar to Bone Hall specimens, except the Hall of Mammals has an updated look and feel, animals in dynamic poses and audio effects and interactives distributed throughout the space. By raising the visitor stopping rate at the Bone Hall to 19%, Skin & Bones was then able to increase the coverage of the exhibition to the same level of another gallery in the Museum, designed anew 40 years later.

As far as the stop duration of participants visiting the Bone Hall during the baseline study, not surprisingly, visitors are more transient with 43.5% of the visitors lingering for less than 60 seconds. Visitors using the app show a different pattern stopping at the display cases that feature Skin & Bones content one to two minutes on average, which is three times more than without the app. These numbers are also higher than what the study at the Hall of Mammals recorded, where visitor stops are under one minute.

The rise in the duration of stops and consequently in the duration of the visit as a whole was expected. Where before visitors found exclusively mounted skeletons accompanied by obscure and unappealing textual information, when visiting the exhibition with the companion mobile app they have access to numerous additional resources whose viewing consumes more time than simply looking at the specimens. Therefore, increase in duration cannot be exclusively linked to greater interest, there is an operational difference in how visitors experience the exhibition with and without a mobile device. To know how much time is added simply from using technology could require designing an app with a neutral or negative rating for comparison, which is outside the scope of this study. Nevertheless, the rise in the time spent at the exhibition and by the display cases is very suggestive of increased engagement and participants were not only compelled to stop more often, their comments (detailed next, p.121) also emphasized what in their opinion was a great improvement to the Bone Hall. Moreover, the average duration of Skin & Bones sessions was recorded as being close to six minutes and a half, quite above the same metric in other museum apps (Alonso & Hayward, 2013; Villaespesa, 2013).

Some authors argue that studies that demonstrate visitors spending more time while using interactive technologies may not mean additional interaction and engagement with the content, but rather more time trying to figure out how to use the device (Marty, 2007b), implying technical difficulties or referring to the period of acquaintance with the equipment. This does not seem to apply to Skin & Bones though. On the one hand the great majority (90.5%) of participants stated being comfortable with technology, even if most of them had never used an app in a museum before, and on the other hand the observation and tracking of participants did not reveal particular difficulties with using the iPad.

These results coming from the comparison of the pattern of visitation before and after a technology layover was introduced to a 50-year-old museum exhibition reveal the interest generated among visitors having a technology-mediated experience.

Besides the visit duration, number and duration of stops, analyzing how the visit path was modified by the introduction of Skin & Bones shows what compels visitors to stop in the absence and presence of technology. Although the long and narrow shape of the Bone Hall forces visitors along a linear path some differences were found.

During the baseline study the display cases with greater attraction power, the most photographed and discussed within participants' groups were the Leatherback Turtle, Perciform Fishes, Gray Whale and Man and the Man-Like Apes. This finding is not unexpected considering their location (see Figure 3, p.55, for reference) – the last three are found at either of the two entrances to the exhibition, where visitors commonly stop while getting acquainted with the subject of the displays. Also, the Leatherback Turtle is located at a funneling passage between two rooms, where the constricted traffic flow slows down. In addition, the Leatherback Turtle, the Swordfish (inside the Perciform Fishes case) and the Gray Whale are impressively large skeletons that elicit "oh wow" reactions and serve as good photo opportunities. This effect of scale has been recorded in other studies, for example during visitor tracking at the Museum's Hall of Mammals (Munteanu & Pekarik, 2005). In that study Munteanu and Pekarik noted visitors were particularly drawn to large specimens like the giraffes, lions and brown bear. Similarly, studies that took place at multiple temporary exhibitions at the Monterey Bay Aquarium consistently showed one pattern of visitation, with traffic moving from the large live animal tanks, to the medium live animal tanks, small live animal tanks, hands-on/interactive exhibits, videos, objects, to text-only displays (Yalowitz & Bronnenkant, 2009). Finally, the Man and the Man-Like Apes case is popular among visitors that stop to compare themselves to primates that are closely related to humans. Thus the location of the objects, in particular the proximity to the entrance, the scale of the objects, and personal interest/preexisting connections were identified as the main attracting factors of the collection in the Bone Hall before the mobile technology.

As far as the visit path during the in-exhibition-mobile-app study, one additional factor shaped the stopping preferences of participants. Figure 29 (p.120) shows the distribution of the number of stops along the stopping points included in the study – 54 display cases, three benches and standing within any of the five rooms.

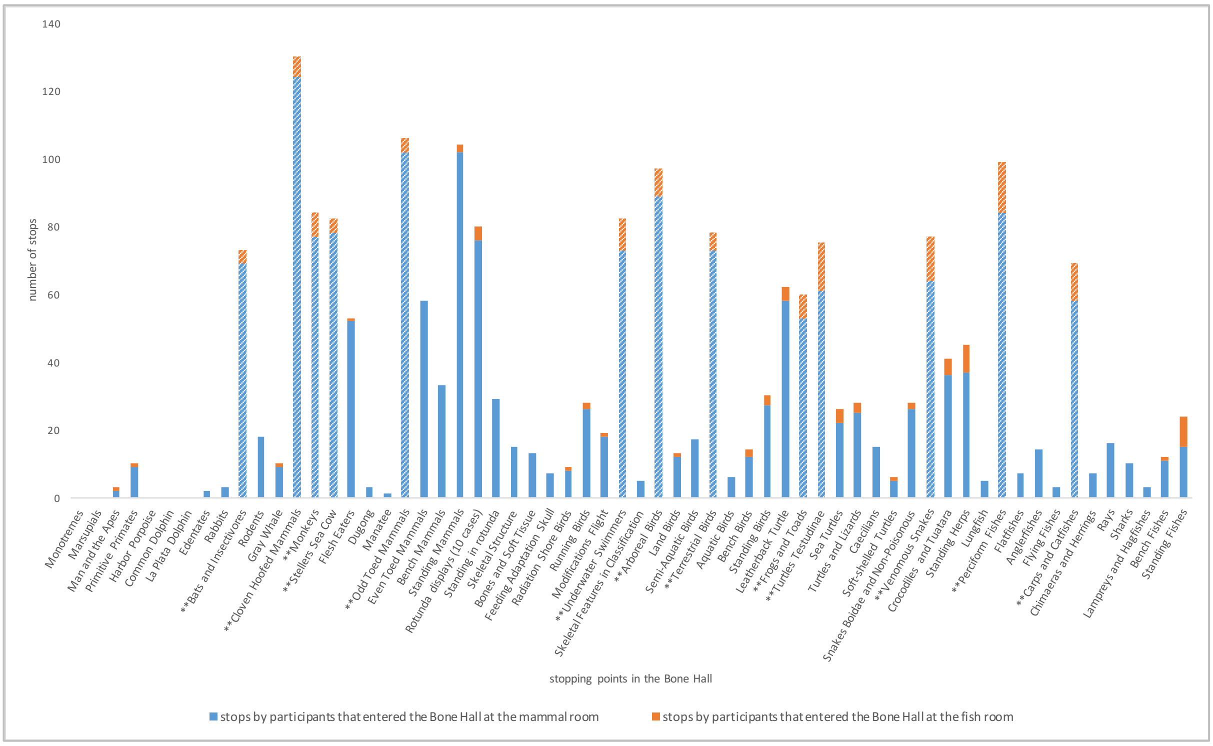


Figure 29 – Distribution of the number of stops at all stopping points in the Bone Hall by participants who entered the exhibition at the mammal room (blue, n=179) and at the fish room (orange, n=20). Double asterisk and patterned bars represent a stopping point with Skin & Bones content.

As expected, the number of participants recruited at the fish room of the Bone Hall was noticeably fewer than those that began the visit at the mammal room. This reflects the natural flow of visitors through the Museum and the typical traffic pattern of the Bone Hall. Observation and tracking of participants from each entrance showed that the factors influencing their visit path are not related to their entry origin.

Noticeably participants stopped more frequently at display cases with skeletons featured in Skin & Bones (represented with patterned bars and double asterisk). The combination of being asked to participate in the study and the additional offerings at those cases naturally influenced the behavior. Participants took minimal time to onboard the app and after seeing the map on the first screen generally proceeded in the Bone Hall in the same sequence as the Skin & Bones animals are displayed, i.e., not prioritizing some over the others. Therefore, personal preferences did not overall influence the visit path or override the sequence of the specimens in the cases along the Hall. The ranking of highest to lowest number of stops at stopping points with Skin & Bones content supports that the location of the specimens and the dimension of the specimens are the top influencing factors.

Among the most visited non-Skin & Bones cases were those with large bodied animals (e.g. Even-Toed Hoofed Mammals case with a Giraffe, Llama and Dromedary Camel skeletons) or with familiar animals (e.g. Flesh Eaters case with a Red Fox, Raccoon, Tiger, among other skeletons). All of the skeletons of marine mammals hanging on the wall, above the display cases and out of line of sight, captured none or very little attention (Harbor Porpoise, Common Dolphin, La Plata Dolphin, Dugong and Manatee).

In conclusion, the location of the objects, scale of the objects and existing familiarity and preferences, in this order, are the factors contributing to the attraction power of the displays, regardless of the technology. When the option to see additional digital content was available, the corresponding specimens became the most visited, but even among them, the effect of location and scale played a role in visitor choices. The fact that Skin & Bones animals became the most searched for profoundly altered what visitors engaged with in the exhibition; for instance, the South American Bullfrog may have been the least attractive among the animals featured in the app, but had it not been included it would have remained essentially unnoticed to the great majority of visitors.

3.2. VISITOR PERCEPTIONS

The perceptions of participants interviewed during the in-exhibition-mobile-app study give an insight into their opinions about the kind of museum experience the Bone Hall offers and about their experience in the exhibition using mobile AR technology.

Whereas participants never directly referred to the collection or to the space as antiquated, they framed multiple problems that are associated with an outdated style of displaying information. Prevailingly, participants mentioned the lack of relevant context and connection.

> "*I think it's easy to look at a bunch of bones and forget about the animal that's underneath, or on top I guess.*"

Also frequently mentioned was the monotony of repeatedly seeing objects that, from the perspective of the non-expert visitor, are all very similar in appearance.

> "[…] *it's easy to blow through this exhibition and be 'it's a lot of bones, it's a lot, of bones.' Exhibition after exhibition of bones. You lose your interest you could say.*"

> "*Bones are just sort of the same color, the same sort of thing.*"

The repetitiveness and the extensive number of objects on display without a familiar organization of content noticeably contributed to the fatigue of visitors, exacerbating their existing tiredness from seeing other tourist attractions and from traveling.

> *"After a while you're tired."*

> *"As you're moving through, you're like skeleton… skeleton… another skeleton…"*

Lastly, the static and non-interactive condition of the exhibition was noticed.

> "*It's slow, a bit tiring if you're always reading things.*"

According to participants Skin & Bones and AR technology circumvented these problems. Namely the app contextualized the specimens and directed their attention to a few curated skeletons, giving them an identity and an emphasis above the rest of the collection.

"[…] *have the visuals to make it more real as opposed to skeletons which dissociate you from nature, from reality*."

"If we wouldn't have had that, we would have just blown right through, stopping at anything that caught our eye. But I wouldn't have seen the catfish and spent any time there, but since it was on there, I saw the video on it."

The app also introduced interaction and motion, which was very appreciated.

"It brings in a different dynamic, using the media. A different way to look at it I guess."

"What's good about it (…) *is that it brings alive the skeleton that's there."*

4. IPOP

The mobile app Skin & Bones' content and structure were designed according to the theory of experience preference IPOP, a four-dimensional construct that proposes museum visitors vary from one another in their relative attraction for Ideas, People, Objects and Physical activities. According to its authors (Pekarik et al., 2014) IPOP is a predictive model, meaning that visitors' experience preferences correlate to the dimensions they most identify with. This research tested this assumption under the conditions of mobile technology which has never been before now.

In order to assist the analysis of the IPOP theoretical framework, the observation and tracking of participants in the in-exhibition-mobile-app study purposely traced two behaviors, "group selection" and "hands iPad to group". When either of these behaviors take place, the decision on the path to take through the exhibition space or the content to watch in the app are no longer individual but rather the outcome of a social agreement. In these cases any app usage data or visit pattern data may not reflect the participant's preferences with respect to their IPOP dimension as identified in the questionnaire. Among the 199 participants of the study, 18 were observed either collectively making choices in the app or handing the device to others in the group, and therefore were excluded from the analysis of IPOP related data.

The questionnaire taken by participants included a set of 12 statements developed by the authors of IPOP, to which respondents declared how much they identified with each one. Following the procedure described previously (p.84) each of the 181 participants was accordingly categorized in the dimension they scored higher for. There were 43 Idea participants, 31 People participants, 33 Object participants, 33 Physical participants, and 41 Multidimensional participants.

Further narrowing of the data was necessary to run the statistical analyses for comparison between participants in the different IPOP dimensions. Only data from participants that used the non-AR-version of Skin & Bones was included in the analysis to eliminate any potential effect of the novelty of the AR technology in the selection of content. If the hypothesized predictive power of the framework holds, there should be a trend showing groups of participants viewing more content and/or for longer periods of time that matches their identified main IPOP dimension. Given that the menu option Skeleton Works has equivalency with the Object dimension and is entirely delivered through AR in the AR-version of the app, and delivered through images and animation videos in the non-AR-version of the app, utilizing the entire data set would potentially introduce unwanted skewing in the data. As such, the data set utilized in the analyses described below is comprised of 24 Idea participants, 12 People participants, 14 Object participants, 18 Physical participants, and 21 Multidimensional participants.

Two methods were used in parallel to analyze the IPOP related data: 1) comparison of content viewing between the five IPOP dimensions, and 2) study of the participant distribution on the five IPOP dimensions within homogeneous groups of content viewing.

Table 8 presents the results regarding the first method by laying out the mean and median values of the different content viewing variables for each dimension; it includes the results of the Kruskal-Wallis H tests.

The absence of significant differences between any of the dimensions for every variable is evident. In fact, trends did not emerge that demonstrate any agreement between the IPOP framework and content choices. At least within the context of this study, there is no predictive power for the content choices groups of people with the same dimension make. For example, on average, participants in all dimensions watched more Animal Life videos and for longer than any other menu option; and participants identified as Object people saw Meet the Scientist and Big Idea videos for longer than participants identified in the other dimensions that align with those content categories.

Table 7 below presents the results of the second method used to analyze IPOP related data. It displays the distribution of participants according to their identified dimension, within each group with a stronger preference for one of the five menu options.

	Idea	**People**	**Object**	**Physical**	**Multidimensional**
Animal Life	12	3	8	11	11
Meet the Scientist	1	2	2	0	0
Skeleton Works	7	2	3	5	9
Big Idea	0	0	2	1	0
Activity	5	4	0	2	1

Table 7 - Distribution of participants identified in the five IPOP dimensions in each participant group with a stronger preference for one of the five menu options.

A comparative statistical analysis was not conducted given the reduced number of individuals overall, in some dimensions and some groups. Nevertheless, results seem to support what the first method had indicated, a non-correspondence between the identified participants' IPOP dimension and the content most viewed in the corresponding menu option in the app.

In conclusion, both sets of results show that the IPOP framework failed to predict participants' preferences for content in Skin & Bones. The negative finding was expressed in the absence of correlation between the identified main dimension of a group of participants and their viewing of content in the app, and groups of participants that viewed greater amounts of content of one dimension were not categorized as having the same IPOP preference.

	Idea		People		Object		Physical		Multidimensional		Kruskal-Wallis H
	Mean	Median	Mean	Median	Mean	Median	Mean	Median	Mean	Median	
Number of Skeleton Works pieces	2	1	1	1	1	1	1	1	3	2	$\chi^2(4)=4.770$ $p=0.312$
Duration of Skeleton Works pieces	0:00:55	0:00:14	0:00:28	0:00:11	0:00:36	0:00:24	0:00:17	0:00:07	0:01:10	0:00:31	$\chi^2(4)=4.538$ $p=0.338$
Number of Animal Life Videos	4	3	3	2	3	3	4	3	4	3	$\chi^2(4)=1.673$ $p=0.796$
Duration of Animal Life Videos	0:04:36	0:03:04	0:02:28	0:01:14	0:04:44	0:03:37	0:05:45	0:03:36	0:05:15	0:04:27	$\chi^2(4)=4.047$ $p=0.400$
Number of Meet the Scientist Videos	1	1	0	0	1	1	1	1	1	0	$\chi^2(4)=5.110$ $p=0.276$
Duration of Meet the Scientist Videos	0:00:35	0:00:09	0:00:55	0:00:00	0:01:10	0:00:07	0:00:59	0:00:17	0:01:05	0:00:00	$\chi^2(4)=5.003$ $p=0.287$
Number of Big Idea Videos	1	1	1	1	1	1	1	1	1	0	$\chi^2(4)=3.506$ $p=0.477$
Duration of Big Idea Videos	0:01:22	0:00:04	0:01:18	0:00:34	0:01:39	0:00:30	0:00:57	0:00:16	0:01:05	0:00:00	$\chi^2(4)=1.938$ $p=0.747$
Number of Activities	1	0	1	1	1	0	1	0	0	0	$\chi^2(4)=4.734$ $p=0.316$
Duration of Activities	0:00:20	0:00:00	0:00:29	0:00:05	0:00:23	0:00:00	0:00:19	0:00:00	0:00:16	0:00:00	$\chi^2(4)=4.161$ $p=0.385$

Table 8 - Comparison between the five IPOP dimensions (Idea n=24, People n=12, Object n=14, Physical n=18 and Multidimensional n=21) regarding the mean and median values of different measures of content viewing by participants that used the non-AR-version of Skin & Bones. Includes the results of the Kruskal-Wallis H tests.

Even though IPOP has been used in other museum exhibition contexts (Beghetto, 2014; Léger, 2014), the model has never been applied to the production of a mobile app. Also, most of the existing case studies in the literature applied IPOP from an exhibition design perspective and with the purpose of increasing visitor engagement through more directed and customized content experiences without testing the predictive power of the model. Therefore, there are no other studies to support or contradict the finding reported here.

It follows that the application of IPOP to the structuring and content development of a mobile app, paired with a physical exhibition, can arguably be considered an entirely different context than when used to design an exhibition that exists exclusively as displays on the museum floor. When studying the "Against All Odds" exhibition – on view at NMNH between the summer of 2011 and 2012, about the rescue of 33 Chilean copper miners that were trapped underground – Pekarik et al. (2014) argued for example, how the displayed objects retrieved from the mine were successful in attracting visitors identified as Object people. Further, the authors characterized the videos as carrying the emotional stories of the rescued individuals, which appealed the most to visitors in the People dimension. According to the authors, the visitors predictably and instinctively approached the different areas in the exhibition space, in accordance with their identified IPOP dimension, after a quick first glance. In other words, Pekarik et al. claimed that there was an unconscious judgment on the potential value of an exhibition asset that was consistent with IPOP preferences. Nonetheless, the first glance at Skin & Bones (or any other mobile app or even digital interactives on the exhibition space), reveals a menu with section titles, which depending on the interpretation of the user, may or may not be intuitive – for instance, the Skin & Bones menu option with content directed at Idea visitors is called "Big Idea", but the menu option for visitors with preference for objects is "Skeleton Works", which may be deemed as less indicative of the content it carries (although formative evaluation of the titles indicated visitors could accurately guess the nature of the content associated with each title). Evidently, opening a mobile app is not as revealing as entering a physical exhibition, the intuitive sampling has fewer clues and opportunities for taking place on the digital realm. As the results of the in-exhibition-mobile-app study indicated, only after random sampling of the different menu options did some participants revisit content types, and several others never even experienced one of each. It is possible that only after a somewhat prolonged exposure to the app, would visitors' content viewing match the identified main IPOP dimension. However, only further studies could test this supposition.

Another factor that could have affected the results is the instrument for collecting data. Originally composed of 38 items, the set of statements was abridged by the IPOP authors to create versions short enough to be combined with other data collecting instruments. This research employed the 12 item version. Arguably the condensed form lacks precision and the high number of participants identified as Multidimensional may indicate poor granularity.

Pekarik et al. (2014) admit that further testing is necessary to ensure the robustness of the different versions of the instrument.

Considering the findings, it is not possible to draw conclusions about the experimental addition of one content dimension to the existing four IPOP dimensions, that is, Animal Life for people with strong affinities to animals. The menu option Animal Life included videos about the roles the animals play in the environment, highlighting the species, their habitats, predators, feeding habits, etc., and did not have a counterpart in the IPOP framework. Animal Life videos proved to be among the most viewed and were evenly selected by participants identified as Idea, People, Object, Physical and Multidimensional. Therefore, the preference for app content related to the ecological aspects of animals did not prove to be tied to participants identified in a particular dimension of the framework, or even to a subgroup within one dimension, which would suggest the existence of more than four categories.

Despite the absence of correlation between the identified main dimension of a group of participants and their viewing of content in the app, some visitors expressed thoughts and preferences in their interviews that were recognized in the different IPOP dimensions. Since participants that were interviewed did not fill in the questionnaire they cannot be categorized using the 12-statement instrument.

- Idea

"*If you're looking at something that makes you think about how it operates, or think deeper about what you're seeing, you're engaged in a way that you aren't if you just sort of…*"

"*And you see and hear about nature, about the woodpecker pecking, and think about how the woodpecker manages to do that. It's interesting.*"

"(…) *some of the evolutionary things like that Big Idea thing that was in there, I like that; I'm really interested in the… you get a lot in the museum, you know, what happened 65 million years ago, I like that concept, I mean those kinds of things; I like some of those things that relate to the evolution part of it, the dinosaur piece of that, kind of the concept of geological time, I like those kinds of things.*"

"*I think it was something that I learned about when I was younger because when I was hearing the information it all sort of came back to me; talking about the way that they sort of just hop around the animals' legs. Kind of gave me the willies... because you think about bats flying and sure you'll see them fly past you, and it's 'ugh, it's a bat'; and then to think about that they also feed on humans, it's interesting; instead of just walking by and be like "look, it's a bunch of bats", it's a specific bat doing all that weird stuff. When you see the teeth, you don't think about it, but then they go into specifics talking about what it is that the teeth do, to puncture the animal's leg; it talked about the bat community and how younger bats sometimes nurse in* *females and don't always get to go out and hunt, so the community comes and supports each other, I thought that was interesting."*

- People

"*You get to hear the people who did the work, who did the studies on them* [the animals], *who found them. This is what they're really passionate about. And I think that's really interesting, being a twenty-something and getting to hear people who actually did what they wanted to do. That sort of thing is kind of encouraging*."

"I do get a lot from the connecting to people and getting that sort of backstory from the exhibition."

"*I thought the meet the scientist thing was pretty cool. It's something you don't normally think about. Puts more of a personal... all of this stuff, somebody had to do it, it's a lot of work involved. It's something I hadn't thought about*."

"*The scientist talked about how she traveled, her whole life, and she was now 70, and we're in our 60s so that was like, 'she's 70 and still doing this crazy stuff?!'. That was interesting to me, it humanized, not only the exhibition but it humanized the people who were in the exhibition*."

"If you look at the sailfish and you listen to the story about his professor [who] *buried a whale for 10 years and they dug it up; that's interesting, that's a story that you don't forget, and the fact that he held the whale tongue and for two weeks he was trying to get that odor off of him. It's stuff like that just sticks with you."*

- Object

"*You could see the skeleton there and then to see the actual anatomy and physiology of the animal working while it's unhinging its jaw, the muscles are releasing the venom into the prey, just kind of be able to take one of these skeletons and visualize how it works when the animal is alive. It's neat*."

- Physical

"*It's slow, a bit tiring if you're always reading things so it brings in a different dynamic, using the media. A different way to look at it I guess, rather than just looking at it and using your eyes, a physical element to it.*"

"*It appears like a physical element, like the bat that's moving, the monkey that's there. And you're holding the thing as well, moving about. It engages different areas of your person*."

This analysis of IPOP based on qualitative data is an approach previously adopted, namely by Léger (2014) at the Canadian Museum of Civilization who sifted through the written comments left on the visitor book of a temporary exhibition. In many testimonies the author was able to identify a stronger connection with one of the IPOP dimensions. In this research such affinities were easily identifiable as well, but not without some incongruences. For example, the number and explicit nature of the comments that resonated with the People dimension was unexpected because the quantitative data revealed a rather small number of participants choosing to view Meet the Scientist videos. The somewhat dissimilarity between qualitative and quantitative data, reinforces the call for further studies regarding the correlation between the dimension a visitor is identified as and their actual preference for content.

5. PRODUCTION MODEL

The mobile app Skin & Bones was developed as a bimodal in-gallery and offsite model, meaning that visitors can use it to accompany their visit to the exhibition and later return to the app to extend their experience when they are no longer in the Museum.

In order to contribute to a better understanding of how a museum app with a dual-location capability is used, this research utilized the GA analytics tool in an all-users study that was not dependent on recruiting participants in the Bone Hall. It parsed the data by location and examined content viewing behavior to verify potential differences influenced by the presence or absence of users in the exhibition.

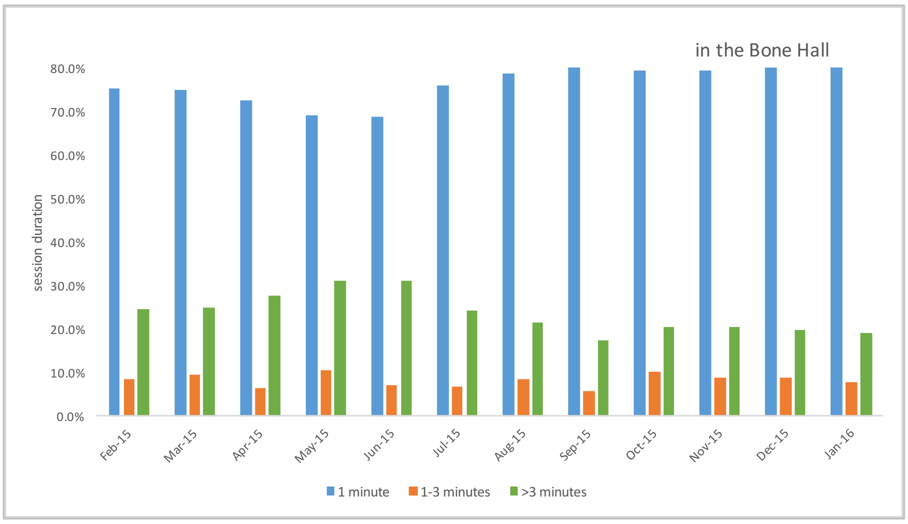
As mentioned previously (p.81), of the three formats of content available in Skin & Bones – AR experiences (Skeleton Works menu option), videos (Animal Life, Meet the Scientist and Big Idea menu options) and activities (Activity menu option) – all except the AR experiences that depended on direct line of sight with the skeletons, were accessible to users offsite. GA monitored the actions of seeing an AR experience, playing a video, completing the video play, and playing an activity; it also collected information regarding the devices used, duration of sessions and ratio of new sessions to returning sessions.

As far as device use, the results show that Skin & Bones was predominantly seen on iPhones (73.7% of all sessions) but also on iPads (24.1%) and less so on iPods Touch (2.3%). If these numbers are compared between sessions that took place in the Bone Hall and outside of the Museum, as seen on Table 9, they indicate users in the exhibition were mostly carrying iPhones, whereas offsite, despite iPhones still being the primary devices, iPads were more commonly used. This is consistent with the probability that visitors to the Museum are mainly carrying phones rather than tablets, for portability and greater use on-the-go, and users outside the Museum having more choice.

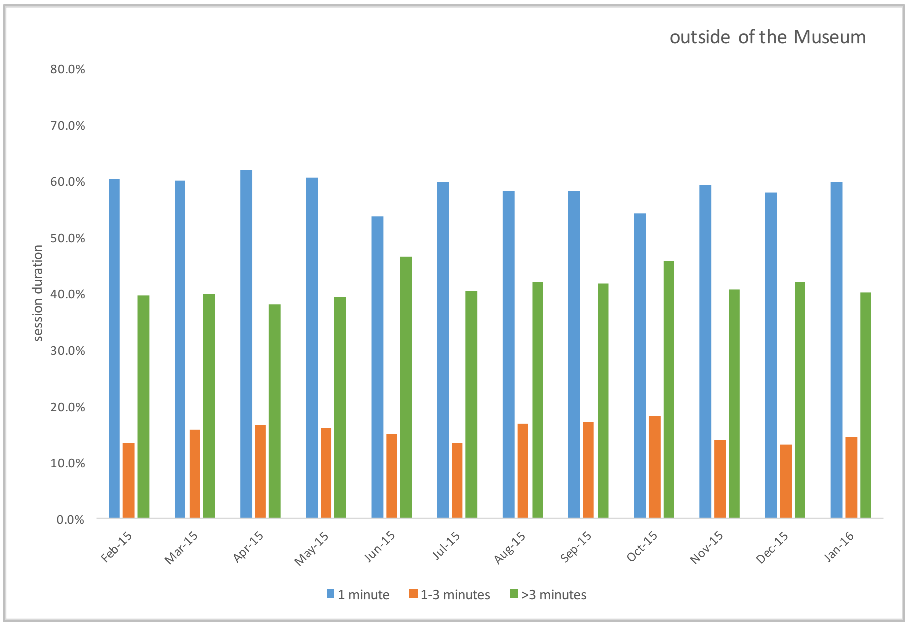
	Sessions in the Bone Hall	Sessions Outside of the Museum
Number of Sessions with iPad	13.4%	34.1%
Number of Sessions with iPhone	82.9%	63.7%
Screens/Session	14	6

Table 9 – Comparison between Skin & Bones sessions in the Bone Hall (n=4,919) and outside of the Museum (n=4,507) regarding the number of sessions with iPad, number of sessions with iPhone and number of screens per session, for the time period of January 2015-January 2016.

In GA terms, a session represents a single period of user interaction with the app and all the interactions that are received within 30 minutes of one another are considered to be the same session. Altogether, Skin & Bones sessions duration averaged 0:05:50. Figure 30 breaks down the metric for users inside the Bone Hall and outside the Museum, for each month of the first year of the app lifetime. There is not a marked fluctuation in session duration throughout the year, except a slight difference for users in the Bone Hall that seem to have longer sessions in May and June when compared to September in particular. This is unexpected if taking into account Museum visitation; September is one of the slowest months (as previously seen on Figure 1, p.52) which would promote longer periods of engagement with the app in an emptier exhibition.



(a)



(b)

Figure 30 – Distribution of Skin & Bones sessions that lasted up to 1 minute (blue), between 1 and 3 minutes (orange), and more than 3 minutes (green), across the first 12 months of the app's lifetime, for (a) sessions that took place in the Bone Hall and (b) sessions that took place outside of the Museum.

Monthly fluctuations may be nearly absent but the profile of sessions is clearly dependent on location. Users outside of the museum tend to conduct considerably more long sessions (>3 minutes) and less short sessions (1 minute), than users in the Bone Hall; but as shown in Table

9, those sessions go through, on average, less than half the number of screens than sessions that take place in the exhibition. One additional aspect of session duration is that they last longer on an iPad – average of 0:08:23 when compared to 0:05:02 on an iPhone – even if the average number of screens per session is approximately the same, 9.3 and 9.2 respectively. Therefore, users outside of the Museum spend more time with the app in longer sessions, and more so if they're using an iPad. They also spend more time with individual pieces of content, even if they see a smaller number of them. This finding is consistent with the high-energy and often loud and crowded environment of the Bone Hall, where visitors feel compelled to move on and keep to an agenda. When outside of the Museum those pressures may no longer be there.

GA is capable of differentiating new users from returning users, through an anonymous unique identifier that tags each device that launches the app for the first time, labeling it as a unique user. Figure 31 compares the percentage of new and returning sessions, for users in the Bone Hall and outside of the museum. It shows that most are new sessions, particularly at the Museum. This was expected given that the app was predominantly promoted inside the exhibition leading to greater awareness and first-time use *in situ*. The augmented content not being available offsite may also have demotivated some potential users from trying Skin & Bones if not at the Museum. The results additionally reveal that the number of returning users was overall low and despite the lack of precise data (due to GA limitations regarding the location of the users) it is probable that revisiting sessions took place mostly offsite. As described previously, other studies conducted at the Museum indicate that the audience all year round is mostly composed of first-time visitors. Thus the returning users of Skin & Bones were likely first-time visitors to the Museum who engaged again with the app after they were no longer in the building.

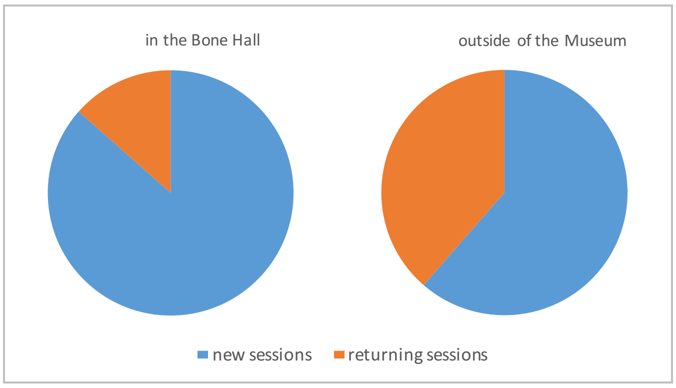


Figure 31 - Comparison between the percentage of Skin & Bones sessions by new users (blue) and by returning users (orange), for (a) users in the Bone Hall and (b) users outside of the Museum, for the time period of January 2015-January 2016.

GA events coded into Skin & Bones to monitor content viewing were included with the first release of the app but the data had some flaws that were later corrected in version 1.3. Therefore, the results discussed below concern the period of March 7, 2015 through January 13, 2016 and not the entire span of the app's first year as the results above do. The following table and figures summarize content viewing results – Table 10 presents the total number of event actions (AR Triggered, Video Play and Activity Completed) in sessions that took place in the Bone Hall and outside of the Museum; and Figure 32 through Figure 34 break down the data by event labels.

	Sessions in the Bone Hall (%)	Sessions Outside of the Museum (%)
AR Triggered	65.3	N/A
Video Play	32.4	87.8
Activity Completed	2.3	12.2

Table 10 – Comparison between the percentage of Skin & Bones sessions in the Bone Hall and outside of the Museum regarding the occurrence of GA event actions AR Triggered, Video Play and Activity Completed, for the time period of March 2015 - January 2016.

Table 10 illustrates the popularity of the AR content in Skin & Bones when compared to videos and activities among users that were conducting sessions in the exhibition. Outside of the Museum when triggering the augmented content was not a choice, activities were more significant in the total of events and users played more videos supporting the effect of content replacement that had been demonstrated before.

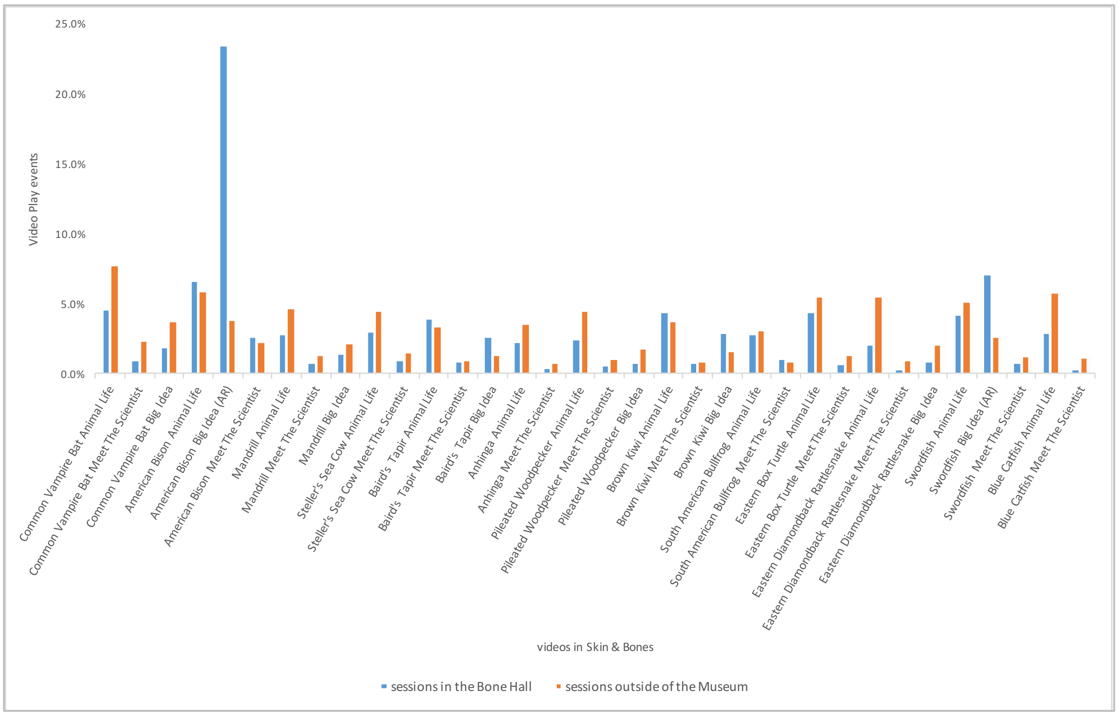


Figure 32 - Distribution of Video Play events during sessions in the Bone Hall (blue) and outside of the Museum (orange), for the time period of March 2015 - January 2016.

On Figure 32 with the distribution of Video Play events, among users in the exhibition the interest surrounding the American Bison Big Idea and to a smaller degree the Swordfish Big Idea stand out, especially when compared to users offsite. These are the content options that include introductory videos followed by AR experiences, revealing once again the attractive power of the technology towards app users. Among those outside of the Museum without access to AR, the viewing rate of the two videos was no different than the other videos in the same category of Big Idea. Augmented content aside, the figure also shows that overall Animal Life videos were played in many more sessions than Meet the Scientist videos or Big Idea videos.

This pattern of behavior cannot have an unambiguous explanation without testing in future studies. Perhaps the familiarity with animal documentaries commonly aired on television creates a preference for the format over engaging with scientists or upper level scientific concepts, or the fact that the Animal Life choice is the first on the screen menu (see Figure 6, p.62) compels users to press it first and more, or even users view it as a nature versus science choice. According to the results of IPOP data the group of users that consumed Animal Life videos the most is not homogeneous in respect to their identified preference dimension, at least when using the instrument developed for the framework, thus no clue towards the interpretation of the result is found there either.

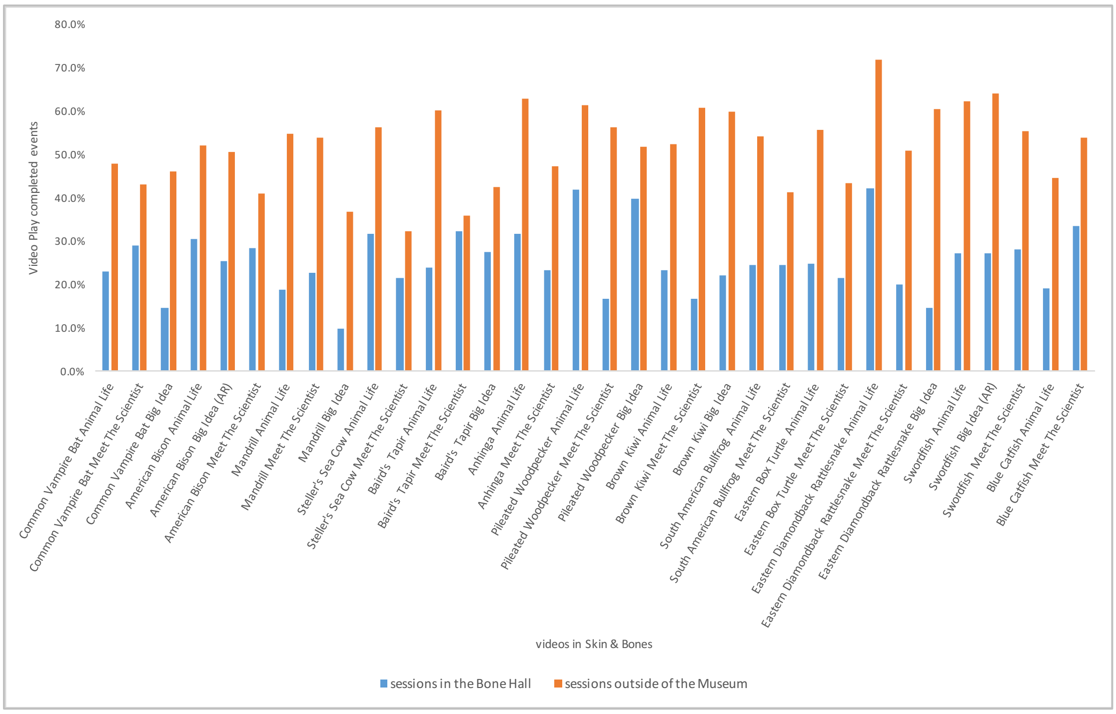


Figure 33 - Distribution of Video Play events with viewing completed during sessions in the Bone Hall (blue) and outside of the Museum (orange), for the time period of March 2015 - January 2016.

One interesting aspect of video viewing is the obvious difference in completion rate between Bone Hall sessions and sessions everywhere else (Figure 33). Across all users outside of the Museum videos were watched more often to the end supporting the earlier findings of greater attention span in an environment likely more favorable to longer sessions and to spending extra time with individual pieces of content. The Eastern Diamondback Rattlesnake Animal Life video holds the record for the video that was most watched until the end. A combination of its short duration (0:01:13) and the general public interest for large venomous snakes are probable justifications for this result.

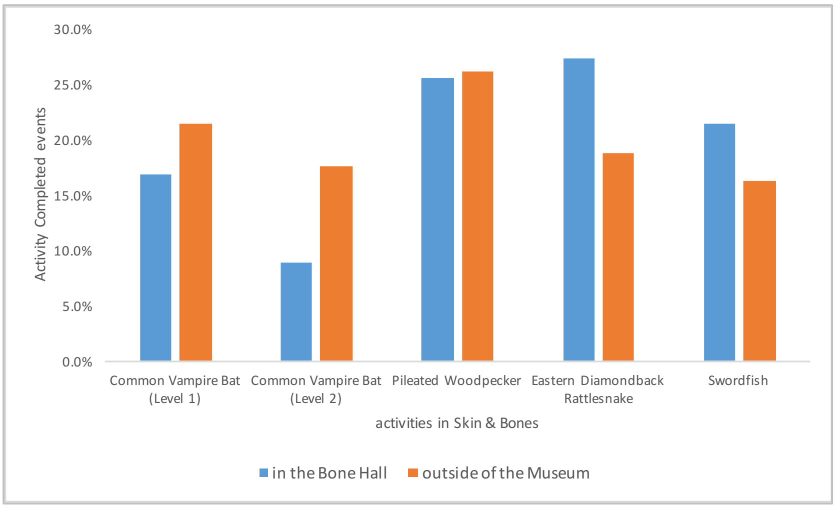


Figure 34 – Distribution of Activity Completed events during sessions in the Bone Hall (blue) and outside of the Museum (orange), for the time period of March 2015 - January 2016.

Figure 34 shows an overall preference for the Pileated Woodpecker Activity and the Eastern Diamondback Rattlesnake Activity, both the most immediate to understand and the most haptic by requiring repeated tapping and shaking of the mobile device, which gives them a playful character. The other activities involve interpretation and selection, and therefore extra dedication. It is relevant to note that the two levels of the Common Vampire Bat Activity were the only to be favored by offsite users, who were also more persistent in continuing on to level 2 after completing the first level with a successful answer. This activity entails extra concentration to listen carefully to the different sounds emitted by bats and hence the finding is in agreement with previous results.

In conclusion, the analysis of the production of an AR app developed in a bimodal in-gallery and offsite model showed marked differences between the two locations in respect to the devices used, the character of the app sessions and engagement with content. Within the exhibition users were impaired by time limitations, agendas, social demands and the conditions of the environment, which likely shortened the attention span of the visitors. Nevertheless, some found value in the fact they could return to the app after the visit, in particular as an educational resource, as the interviews with the participants of the in-exhibition-mobile-app study revealed.

> Visitor 1: *"surely we didn't do all of the videos either, because we're pressed for time and we don't want to spend a whole lot of time in one exhibit, and some of the videos are like three and half minutes long."*
> Visitor 2: *"what if you were to download the app, could you watch this stuff later?"*
> Research Assistant: "*Yes.*"
> Visitor 2: *"so that I think it would be... if we actually had the app to be able to go back and sort of re-watch that stuff."*

> *"It would be a way to share knowledge, and not everyone is going to be able to come out. 'Here's all the pictures and video we took and also there's this', you have an iPhone and pull this out, 'this is just one section of one of the museums to give you a taste of what's there'."*

> "*And it could be used for the kids too. So they come on a tour, they go back to school, they have to do something for class about it, they could bring it back up.*"

The idea expressed by participants of the app as a continuation of the Museum meets perfectly the museum professionals' argument for the use of mobile as an extension of the experience and engagement. Creating an experience that is rich and adaptable to the environment is also supported by the findings of this research. The multivariate analysis reflected the advantages of offering different formats of content (AR experiences, videos and activities). For instance, participant groups such as clusters 5 and 6 gave preference to watching videos despite having AR content available to them and viewed videos in greater number and for longer than visitors in other clusters. Although there was great overall acceptance of AR technology among participants in the exhibition, certain niche groups still choice differently, raising the value of museum products that are diverse and thus customizable for preferences and location.

6. CONCERNS AND CHALLENGES

According to the literature review there are several concerns and challenges that afflict the production of mobile products in a museum context, some of them being particular to projects that adopt AR technology. Museum professionals are concerned that mobile AR in exhibitions may detract from the museum experience, replace the museum experience, or simply constitute an expendable gimmick. They are also confronted with challenges such as deciding the duration of the content offered, ameliorating visitor difficulties when onboarding the AR experiences, and reducing the design impairments presented by indoor exhibitions (e.g. blockage of the line of sight between visitors and the features to augment, hitches on accessing the internet, and high noise level in the galleries).

This research analyzed as a case study the production of the mobile app Skin & Bones under the light of these assertions, using the perceptions, pattern of visitation and content viewing data of participants in the in-exhibition-mobile-app study and all-users study.

- Museum enhancement and expansion

The detraction from or replacement of the museum experience derived from using Skin & Bones while visiting the Bone Hall as an area of concern was never mentioned by the interviewees. The app was never referred to as a distraction or as a self-sufficient tool they could use instead of visiting the Museum. On the contrary, they considered the app as an enhancement to the exhibition and an improvement to the sort of experience they were already having, such as allowing for a self-directed and paced visit where they made their own choices. Without the app, visitors enter the Bone Hall without a map of the exhibition, no end in site, and they are facing hundreds of skeletons without any tools to navigate and make choices.

> "*So that was really cool. And I like that it's self-paced so that if you didn't want to do everything you could just stop… you could pick and choose what you could listen to*."

> "*The good thing with it is that all people have different interests, so if someone wants to know more about that fish, someone wants to know more about birds, then you can choose what you want to see more about*."

> "*If you have something like this you can focus on only one. And then you're looking at everything else within the exhibit, and reading everything; for me, it made it more pleasurable."*

Some participants commented on the informal learning aspect of the app. They recognized they were learning in ways that did not resemble learning in the classroom and others saw it as an opportunity to dive deeper and get more information.

> "*You can learn something without having to, you know, learn something*."

> "*It gave us a lot more information. It was nice to kind of sit here, look through it, and see the skeleton and you could go back and look at the information*."

> "*I'm always interested in learning new things. So when there is stuff I don't know about, I want to learn about it, so it's interesting to be able to watch videos on these animals that I know nothing about and learn a little bit, even if they're only two minute videos they've got good information in them*."

Participants made comparisons to traditional museum audio tours referring to Skin & Bones as superior because it was a self-directed and modular experience, whereas audio tours tend to be linear.

> "*You have in other museums the headsets and guided tours but then you have to listen to everything about the topic that doesn't interest you. If you had an app covering the museums, then you can choose what in the area interests you and you can skip what doesn't interest you*."

The exacerbation of a "heads-down" experience locked to mobile devices that hypothetically distracts and disengages from the surroundings (Hsi, 2003; Woodruff et al., 2001), and the spatial disconnect witnessed by some authors regarding geo-located AR experiences (C. B. Madsen et al., 2012; Wither et al., 2010) were not observed in this research either. Skin & Bones direct reliance on the exhibition specimens to trigger the augmented content strongly interconnected the real and virtual environments, which did not go unnoticed by participants.

> "*You could see how it actually moves based upon its skeleton*."

This reinforces the idea that mobile AR technology has the unique potential to foster visitors' exploration of their surroundings, if image or object based AR is employed. The object and its interpretation became one from the point of view of the visitor, coexisting on the display and depending on one another.

Gimmickry was also not a fault raised by participants in the case study in this research. The purpose for developing Skin & Bones with AR technology was to repair an exhibition without physically touching the historic design, while allowing an antiquated museum experience to subsist and simultaneously coexist with an up-to-date and more engaging version of itself. Never was the goal for using the technology to seek market share or attract younger audiences, but instead it was the fostering of a positive Visitor Experience. Participants' responses confirmed the value and effectiveness of the digital tool.

Even though the concerns identified in the literature and discussed above were unfounded with respect to this case study, several of the challenges tied with the production and implementation of mobile AR technology in museum environments presented themselves, and some to an extended degree. They are detailed next.

- Onboarding Augmented Reality and line of sight

Data retrieved from the research iPads during the in-exhibition-mobile-app study indicated that the 102 participants that used the AR-version of Skin & Bones selected the Skeleton Works menu option with augmented content a total of 360 times. However, observation and tracking data showed that only 313 of those times did participants actually experienced the technology – at 22 occasions participants were not close to the corresponding skeleton and could not have triggered AR (most often it happened when they were initially browsing the app or trying to get to a different screen); and at 25 instances participants were by the matching skeleton but did not succeed in the triggering process for reasons discussed below. Failure rate in activating AR in the Skeleton Works menu option was then 6.9%, which is relatively low when considering that study participants received no previous instruction on how to operate AR and the great majority had never encountered the technology before.

The specimens where participants saw their efforts fail were the Eastern Diamondback Rattlesnake (36% of the failed attempts), Common Vampire Bat (32%), Steller's Sea Cow (12%), Pileated Woodpecker (8%), Swordfish (8%) and Anhinga (4%). All the attempts to trigger AR from the Mandrill and the Blue Catfish were successful. The cases where these two animals are on display differ from most of the other Skin & Bones cases in that 1) among the several specimens they contain, the skeletons featured in the app are the largest and stand out from the others; 2) albeit large when compared to the other specimens in the same case, the Mandrill and the Blue Catfish skeletons do not have extreme dimensions that require the user to step back far from the case to trigger AR; and 3) both display cases are located in corners of the Bone Hall, away from visitors' main traffic flow. Therefore, the two specimens were easy to find and identify inside their cases, and the triggering process was not greatly affected by the volume of visitors in the exhibition space getting between the app user and the target skeleton.

The Samoan Fruit Bat skeleton was repeatedly mistaken for the Common Vampire Bat as it is right next to the featured animal and comparatively larger, a similar problem to the Semi-Aquatic Birds case where the bigger Loon misguided participants away from the Anhinga skeleton. The Steller's Sea Cow was missed by some due to its position high up above the cases and above eye level, and some users failed to step back enough to see the entire skeleton on their screens. This was also the problem at the Perciform Fishes case where the sizeable Swordfish requires distance from the case to activate the AR content. The Venomous Snakes case that includes the Eastern Diamondback Rattlesnake elicited the greater number of AR trigger failures due to the location of the skeleton on the right sidewall of the case; whereas all the other AR experiences are activated from one skeleton, the augmented content for the Rattlesnake is triggered from the entire front of the case. This proved confusing to some participants that were observed aiming at the skeleton on the side, despite the instructions in the app.

Thus, the factors that proved to effect a successful onboarding were the scale of the triggering object in relation to the surrounding objects, the position of the object in the display case and in the exhibition, and the distance between the user and the object.

High visitation in the Hall sometimes did not permit participants to step back as much as necessary, or visitors walked between the display case and the participants holding the devices. This compromised the required clear line of sight between the user and the object which either prevents the experience from triggering, or abruptly interrupts it. Some participants felt socially pressured and refrained from lingering on a given case, feeling as though they were getting in the way of other visitors.

> "[…] *I felt like I got in the way of people since there's a lot of traffic. So it was just kind of, 'let me stand over to this side so that people can see the case'.*"

> *"The bison is just so big that I couldn't fit it all in there, I think I would have needed to back up but then I didn't want to be in people's way."*

In addition to the Skeleton Works menu option that offers AR content in Skin & Bones, the options Swordfish Big Idea and American Bison Big Idea also have augmented experiences but preceded by an introductory video. Only after seeing the video in full is the user prompted to hold the device to trigger AR. These two pieces of content were treated differently than the other AR content included under the Skeleton Works category due to the added complexity of the ideas requiring an introduction. The account paired with the American Bison explained the evolution of animal species through principles of common ancestry and bone homology, and with the Swordfish the content covered the metamorphic life cycle of fish. These are intricate subjects that shown exclusively through superimposed content onto the displayed skeletons would have been confusing to the viewers and complicated to produce.

The 102 participants that used the AR-version of the app in the in-exhibition-mobile-app study selected either or both the American Bison Big Idea and the Swordfish Big Idea a total of 70 times; but the observation and tracking data showed that only 33 participants actually experienced the augmented content – at 5 occasions they were too close to the display case to successfully trigger AR; and at 32 instances they either did not watch the full video, or did not hold the device to see the second part of the experience. Therefore, 45.7% did not find the video compelling enough to complete its viewing, were anti-evolutionists, or did not realize it was followed by an AR experience.

Data from the all-users study confirms these results. Figure 35 shows how the American Bison Big Idea and Swordfish Big Idea options were considerably less triggered than all the others, but Figure 32 (p.133) had revealed that the preceding videos were the most played. In Figure 33 (p.134) the apparent discrepancy is resolved – only 27% of the American Bison Big Idea and 25.4% of the Swordfish Big Idea video plays were completed.

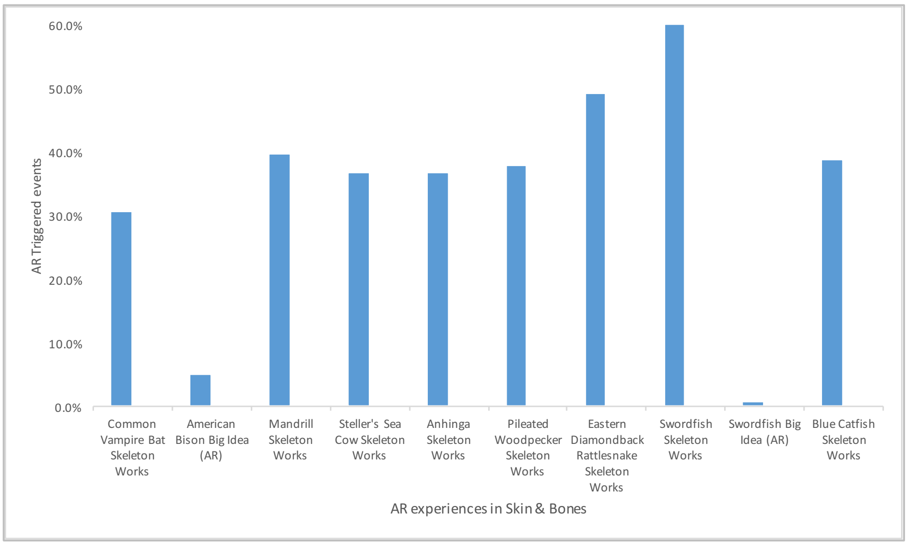


Figure 35 – Distribution of AR Triggering events during sessions in the Bone Hall, for the time period of March 2015 - January 2016.

Notably, using video to set up an AR experience introduced inconsistency with the process of triggering AR at Skeleton Works pieces and caused difficulties. Beyond raising the question on how the user experience and on-screen instructions can be improved to ameliorate this situation in Skin & Bones, a deeper question concerns whether conveying complex information through AR is even possible? Is it possible to use augmented content to do more than skinning an object or demonstrate its function?

The subjects portrayed are intricate, yet fitting with the setting of a natural history museum and a taxonomy based collection. In fact, some of the few participants who overcame the hurdle of the video and AR combination, stated their interest about the content.

> *"I loved the augmented reality breakdown that showed the family chain based on specialized ankle."*

> *"The feature on the differences between larval fish and adult forms was interesting."*

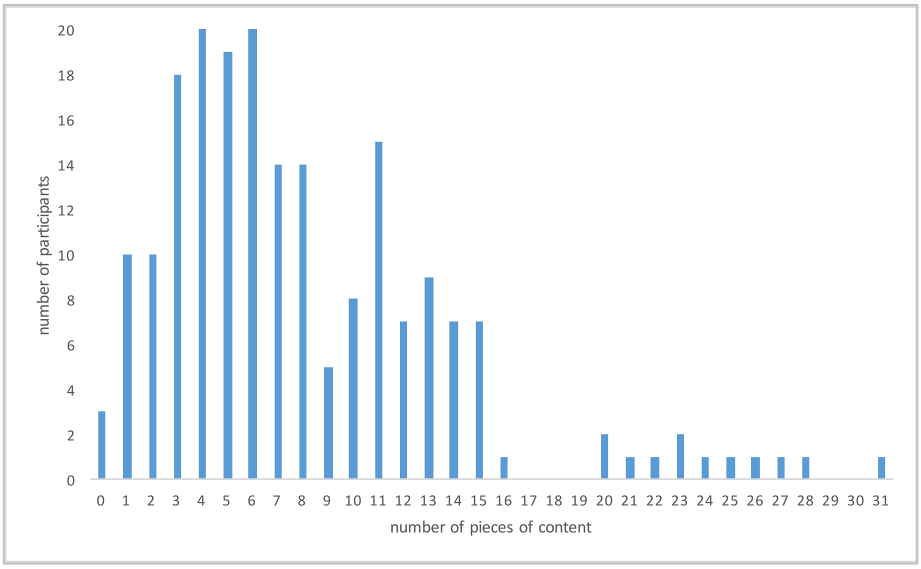
One of the impairments of telling a complex story with AR can be the longer duration of the content throughout which the visitor has to hold the device. Another, the added volume of information that can clutter the display and be confusing when superimposed onto the real background. The amount of augmented information presented through mobile AR and its placement on the device displays have been raised by some authors as design factors to be mindful about (Li & Duh, 2013; Stedmon, Kalawsky, Hill, & Cook, 1999). As mentioned in the literature review, cognitive overload has been the subject of concern when contemplating the use of AR (Dunleavy et al., 2009; Klopfer, 2008). Some of the solutions suggested by different authors – starting the AR experiences in a simplified structure and increase complexity over time (Perry et al., 2008); replacing text with audio (O'Shea et al., 2009); using video narrators of the same age as students (Dunleavy, 2013); scaffolding each experience at every step to achieve the desired learning behavior (Klopfer & Squire, 2008) – are either specific for formal education settings or could only be applied in a museum exhibition environment facilitated by docents.

Therefore the complexity of the augmented information and the best practices to deliver it in museums is a subject that warrants further thought and testing.

- Duration of content

It is well known through museum studies that the majority of visitors do not spend long periods of time at museum exhibitions, thus the amount of content and visit duration are key variables to consider, not only to avoid exhausting the visitor but also to ensure the main messages are transmitted. AR experiences hypothetically are more delicate to handle given that holding the mobile device in place for the extent of the video or animation is required and prone to being strenuous.

The average viewing of Skin & Bones content, both in number of pieces and in duration, proved to be low-medium and not unlike what is usual in museum exhibitions, i.e., with a few outlier participants who saw far more and for far longer than the bulk of visitors.



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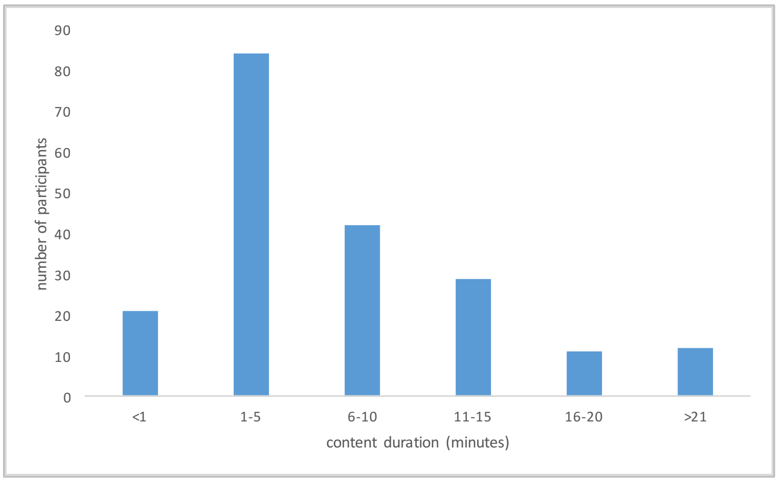

(b)

Figure 36 - Distribution of participants (N=199) according to (a) the number of pieces of content seen, and (b) duration of content viewed.

Participants in the in-exhibition-mobile-app study ranged from seeing no content at all (just browsed the screens but never played a video, activity or engaged with AR/AR-equivalent content) to engaging with 31 pieces (out of a total of 46), as shown on Figure 36(a). Most participants enjoyed content for 1 to 5 minutes, but several as long as over 21 minutes, as shown on Figure 36(b); the average duration of content viewing was 0:08:10. These findings reveal that engagement with Skin & Bones was longer than what has been recorded for some other museum apps – for example, the American Museum of Natural History mobile app Creatures of Light, available at the companion exhibition in stationary iPads, was used in average for 0:02:28 (Alonso & Hayward, 2013), and sessions conducted with Tate Museum apps lasted between one and three minutes (Villaespesa, 2013). Neither of these apps included AR technology.

Despite the longer than usual average engagement with the app, interviews revealed that some participants felt that by using the app they were threatening their overall goal of seeing all the Museum has to offer in the time they had. This was especially felt among those under the impression they were supposed to watch all of the content.

> "*Probably not patient enough to watch all of this*."

> "*In this big museum, if you should spend more than five minutes on each display, you take two days to get through all of it.*"

> "*Surely we didn't do all of the videos either, because we're pressed for time and we don't want to spend a whole lot of time in one exhibition, and some of the videos are like three and half minutes long*."

> *"Some of the ones we saw, we stopped after, I don't know, a minute or two. We're tourists so we have to proceed."*

Others however did not find the content too long, and even remarked it was informative for its short duration.

> *"When I got tired, I sat down and punched the skeletons so I could actually see what was there without standing for 20 minutes."*

> "(…) *even if they're only 2 minute videos they've got good information in them*."

Interestingly, the requirement of holding the iPad for the entire duration of the animated AR experiences was commented on only by one participant and never were participants observed lowering the iPad while watching the augmented content, dismissing the idea that the operation of the technology would inevitably be regarded as strenuous.

> "*I think I would like it better if you didn't have to hold it up the whole time, if you could just snap a picture and then it comes to life from there.*"

In conclusion, the findings concerning the amount and duration of content are more revelatory of the typical profile of the visitors to the Museum than they are related to AR technology and potential implications of how it is activated. When realizing the rich and numerous content of Skin & Bones participants felt overwhelmed with the idea they were supposed to watch its entirety and the concern over keeping up with a busy tourist agenda even distorted their perception of time – whereas the average duration of a piece of content in the app is 0:01:50, with the longest being 0:02:42, one participant remarked "(…) *some of the videos are like three and half minutes long."*

- Internet Access

Internet access, one of the most discussed difficulties of indoor museum environments as covered in the literature review, was also examined using data from the case study. Wi-Fi access is provided at no-cost and without password protection in the Bone Hall, the only unique requirement being to agree to the terms and conditions of an agreement screen. However, the results of the all-users study show that a substantial amount of visitors at the exhibition did not take advantage of the free Wi-Fi and used their own data plan to download and operate Skin & Bones.

This finding was discoverable through the examination of GA data from users inside and outside of the Bone Hall. The event action "AR Triggered" could only be recorded in sessions taking place in the exhibition. However, the GA method of locating the user is based on the location of the internet service provider rather than on the physical location of the mobile device, so only an AR trigger could absolutely locate visitors in the exhibition that were not using the Museum Wi-Fi but rather their own data plan serviced from outside of the city. Data analysis reveals that 38.2% of all recorded "AR triggered" actions were part of sessions reported offsite. Thus a large percentage of visitors to the Bone Hall did not connect to the Museum's Wi-Fi to download and use Skin & Bones.

One the most likely reasons for this outcome is that participants were not aware of the courtesy Wi-Fi despite the signs spread throughout the gallery with access information. Another is that they encountered a problem when establishing the connection and had to use their own data plan. As discussed in the research limitations (p.83), the internet access points in the Bone Hall were impaired by the crowds in the gallery and connection speed at times was severely decreased, which may have interfered with the download and operation of the app. These are not uncommon tribulations that museums run into, and a similar situation was identified at other institutions (Davies, 2012; Thian, 2012).

Participants were aware of the logistical hurdles that connecting to the internet sometimes presents and commented about it during the interviews.

"*I'm from the UK and I don't actually have the internet.*"

"*Walking around, to download it, you need a Wi-Fi spot. That's the trick*."

- Noise

The last challenge for indoor museum AR experiences identified in the literature review are the noise levels that some galleries are prone to as a consequence of the visiting crowds. Difficulty with listening to Skin & Bones audio content proved to be the greatest challenge recorded in the case study. The problem was extensively observed during observation and tracking, as participants took the iPads closer to their ears and increased the volume, and repeatedly voiced their difficulty during the interviews.

"(…) *we're leaning in 'cause it's noisy here*."

"*I'd say headphones are probably a necessity because it's kind of hard to hear*."

"*Started watching the first one for about a minute, then I couldn't really hear it. It's kind of annoying to watch the subtitles, then try to watch the video, your eyes going up and down*." "*I'm not the type of person who can watch foreign movies*."

"I couldn't hear the videos. If you were to integrate some sort of noise canceling headphones that go over the ears, I think then you'd be on to something."

This complements what was previously discussed regarding users inside the Museum being less attentive and available to watch content in the high-energy and loud environment. As mentioned, even the completion rate of the Vampire Bat Activity, which is entirely audio reliant evidenced the audio problem, as users offsite were far more successful in the game and played it more than visitors in the Bone Hall.

The impairment of the Visitor Experience as a result of the noise problem is multifaceted. On the one hand visitors are limited in the content they view, predictably become frustrated and less satisfied with their experience. On the other hand, the social aspects of the visit are hindered. The necessary use of a headset or earbuds in order to listen to the audio individualizes the experience and isolates the visitor, which did not go unnoticed by participants.

"*I don't know if two people can really use it, because if you have headphones it's mainly one*."

"*Since I'm here by myself it was good, but I'm trying to picture it in a family setting… you'd have to share the earbuds with the kids*."

Feasibly, this problem influenced the rating of Skin & Bones for not strongly promoting social experiences as identified by comparing participants who saw AR with participants who saw AR-equivalent content, and by the multivariate analysis.

V. CONCLUSION

This research was designed to address the compelling need of the modern museum to understand its audiences, their preferences, behaviors, and responses to technology mediated experiences. Digitally driven disruptive museum practices are replacing traditional methods of meeting visit expectations and the void in the knowledge regarding the true effect and reach of such practices is immense.

The focus is on the Visitor Experience with AR technology delivered through mobile devices in museums. Regarded for being capable of merging the experiential and interpretive aspects of perceiving an object, the promise of AR is to reinvent the interaction between visitors and materials on display, yet not enough is known about the reality of the claim, the process of the interaction or the resulting experience of the visitor.

Through this research an AR mobile app was designed, tested, developed and implemented as a companion to a vertebrate skeleton exhibition in a natural history museum. In a controlled setting, the use of the app by visitors to the exhibition and their experiences is the focus of the research, with further studies on the bimodal use of the app onsite and offsite and the theoretical framework used to design the app and its content. The findings confirm unambiguously the positive influence of AR technology over the Visitor Experience, reveal differences in behavioral uses of the app onsite and offsite, and question whether there is any predictive power when using the IPOP theory of visitor preferences with mobile technology.

AR was shown to increase the interest for and engagement with the content on display by promoting more visitor stops along the exhibition and by heavily shaping content choice. The images and animations superimposed onto the skeletons were watched significantly more and for longer periods of time when compared to video content, to the extent of inducing a replacement effect – if AR experiences are available visitors see less of other content formats. Additionally, the technology determined content preferences. The objects that are augmented became visitors' favorite objects and the source of the augmented content became the favorite section in the app.

The technology also has a positive influence over visitors' satisfaction level and in meeting their experience with previously existing expectations. The literature review highlighted how some authors consider these two factors as critical to affecting the Visitor Experience. Namely de Rojas and Camarero (2006) believe visitor satisfaction to be dependent on the perceived cognitive and emotional aspects of the visit. According to them, the quality of the experience from the visitor's point of view depends on the visit meeting or exceeding the existing expectations. Interestingly, the results of this research found a strong association between AR technology and visitor satisfaction and surpassing of expectations when all study variables were analyzed versus when they were tested in isolation. This may have been the result of methodological interferences, yet it supports the holistic approach that many authors endorse for the study of the Visitor Experience. Only when considering simultaneously visitors' sociodemographic information, content viewing and content preferences, ratings of satisfaction and meeting of expectations, and the degree to which different categories of experience were stimulated (including cognitive and emotional experiences underlined by de Rojas and Camarero), that a well-defined correlation between AR and the Visitor Experience emerged.

This holistic framing of the experience that takes into account multiple human dimensions is a common thread linking Visitor Experience frameworks and UX frameworks. This justifies the adaptation of a set of measurements developed within the field of UX, which are specific to analyzing the user experience with mobile AR services, to the setting of a museum exhibition. The outcome is a dedicated research instrument, specific yet flexible. Of all categories of experience considered – instrumental, cognitive and epistemic, emotional, sensory, motivational and behavioral, and social – AR technology was shown to enhance experiences of emotional and instrumental nature more than other types, and had the least influence on experiences of a social nature.

In part, this outcome derives from the novelty that AR represents in the way to go about navigating an exhibition, especially when the majority of visitors has not been in contact with the technology before. Fostering emotional experiences are among what museum professionals strive for the most. They know that feelings of amazement and surprise about the unique and irreplaceable museum collections promote return visits and gratification. As stated by Hassenzahl and Tractinsky (2006) "*a product's novelty and the challenges it provides, contribute to its hedonic quality, which is relevant because it promises fulfilment of an underlying human need – a need for being stimulated, to perfect one's skills and knowledge, to grow*." (p.93). To be stimulated by cultural heritage, art, science and nature is one great driving force of audiences for visiting museums and AR technology has the capacity to excite and engage.

Depending on the future level of the penetration of AR technology into the museum environment the novelty effect might diminish and the emotional experiences become even more dependent on the nature and quality of the content design rather than an artifact of contacting the technology for the first time. Nevertheless, strongly nurturing instrumental experiences as AR technology is shown to be capable of aligns with the modern museum direction and argues for its adoption. The sense of connectedness to the collection and exhibitions, and the personal meaning gleaned by visitors from their experiences with AR are primary for making a museum stand out and be relevant to its visitors.

As far as social experiences, even if AR technology as delivered by mobile devices cannot be regarded as a major facilitator, it can be integrated in tools that are more intentionally designed for that purpose. Gamification through AR has been successfully attempted by some museums and particularly targets social interactions.

Social interactions between unrelated visitors promoted by the use of the technology were an unexpected side effect. Authors have reported it before (Schavemaker et al., 2011; Thian, 2012) and described it as the "honey pot effect", i.e., the progressive increase of the number of people in an area because others are there standing and visibly showing an interest for what they are observing (Brignull & Rogers, 2003). The honey pot effect has not been explored in depth by museums and it can be an interesting social interaction to encourage, as long as the novelty and surprise of the technology is strong enough to elicit this effect.

In brief, the interpretation of the findings of this research support that the Visitor Experience mediated by AR technology is affected positively in any museum setting and that the results are not particular to the case study. By utilizing an augmenting digital tool museum professionals can expect to influence visitors' engagement and preferences as reflected in their patterns of visitation behavior, content viewing, satisfaction levels and experiences.

Additional factors were observed to have an influence over the Visitor Experience. The size-dimensions of the objects displayed and their location within the exhibition determined to a great extent what visitors saw despite the use of the app and the use of AR technology. Also, the entrance narrative, defined by Doering (1999b) as the visitors' interpretations of the world, the information they have retained about a subject, and their personal experiences, emotions and memories came across in the study's results. App and exhibition content preferences identified by some study participants were justified by existing predilections for displayed animals, familiarity, or were linked to memories or experiences unrelated to the museum and to the AR technology. Doering postulated that the most satisfying experiences are those that resonate with the visitors' entrance narrative and confirm their existing views and expectations. Even if for most visitors either the use of AR technology overruled the effect of the entrance narrative or theirs was not very significant in that environment, for some others the experiences were indeed modulated by their background.

Recalling the contextual model of Falk and Dierking (2000), the authors consider that the individual's meaning-making in museum exhibitions is the product of the interaction of three contexts over time – the visitor's personal context, the socio-cultural context and the physical context. Whereas the display of sizeable objects or their location is part of the physical context of the visit and thus mostly under the control of museum professionals, the entrance narrative is entirely part of the visitor's personal context. A digital experience delivered through AR on a mobile device is included in the physical context according to Falk and Dierking (2008), yet as the findings confirm the overall Visitor Experience is the product of more than can be determined by the technology.

The second focus of this research was on exhibition settings enhanced by AR technology. According to the literature, AR can possibly overcome some of the limitations of antiquated museum spaces by introducing up-to-date content delivered in a novel and captivating way without the need for a physical renovation.

The introduction of the mobile AR app Skin & Bones to the aged Bone Hall exhibition that was used as a case study undeniably had a reinvigorating effect while curtailing several problems identified by visitors to the space and displays. They mentioned the lack of context and connection with reality, repetitiveness in the number and type of objects and, above all, absence of multisensory stimulation (through interaction, motion, sound). These are not exclusive problems to the exhibition under study, they are in fact predominant across antiquated museum settings once designed to let the objects speak for themselves without making overt connections to individuals and the world of their experiences. The potential interpretations inherent to the collections and relationships between the objects do not carry over to the visitors that, as non-specialists, need added curation to facilitate experiencing the information. Modern mechanisms for telling stories and communicating ideas can transform content to experience and this will capture and engage their attention.

Upon the use of the technology visitors' engagement multiplied as reflected in extra and longer stops, lengthier visits, and in a new pattern of visitation that included displays barely attended before. The digital makeover fostered a 19% level of visitor coverage of the exhibition whereas it was close to 0% before. That is a similar level to what is recorded for another exhibition in the same museum, which was designed anew 40 years later. Despite a significant increase in the number of stops, covering 19% of an exhibition may not seem like a substantial amount from the point of view of museum professionals who strive to capture and maintain visitors' attention. According to Serrell (1998) who compared visitor behavior data across 110 exhibitions, visitors typically view only 20% to 40% of an exhibition. The author considers these to be small numbers resulting from the apparent non-thorough and non-systematic way that visitors make use of exhibitions. Were they to browse the space in a comprehensive fashion (Shettel, 2001) and pay closer attention (Serrell, 1997), they would make a better use of their time and benefit more from the museum's offerings (Falk & Dierking, 2000). However other authors, arguably more updated in current museum practices that focus on the visitors and on their motivations, advocate that curiosity is what drives the approach to an exhibition and the strategy employed does not conform to the standard of diligence (Rounds, 2004). It is also questionable to compare museums that charge a fee for entry to NMNH, which is cost-free and sits alongside many other free entry museums that can be reached by walking a few minutes. Visitors typically visit two or three, which strongly influences how they spend their time, and these museums are large. NMNH has more than 10 exhibitions, so under these conditions 19% is a good number.

The goals of the case study mobile app – resuscitating an antiquated exhibition by increasing the enjoyment of visitors and meeting their expectations, while preserving the historical physical design, avoiding a large-scale renovation and the considerable spending of resources – were accomplished. This kind of intervention promises to be successfully replicated in other similar environments. Beyond its proven success in repairing common problems to antiquated exhibitions, it is an elegant and visitor-minded solution that creates two alternative modes of visitation – one that preserves the legacy collections and museum practices for niche audiences and object-focused educational methods, and simultaneously targets the population at large, keeping up with modern demands and expectations. It also does not compromise the emphasis on the museum collections, as the virtual overlay is dependent on and connected to the tangible exhibition.

The content and structure of the case study mobile app were designed according to IPOP, a theory of experience preference and a four-dimensional construct that proposes museum visitors vary from one another in their relative interests for Ideas, People, Objects and Physical activities. According to its authors (Pekarik et al., 2014) IPOP is a predictive model, meaning that visitors' relative attraction to the four dimensions influences what they pay attention to and what they do in a museum exhibition. If this claim holds true, museum professionals would have a powerful tool at their disposal for designing exhibitions based on known visitors' preferences. They could design museum spaces and real and virtual offerings accordingly. This research tested the predictive power of the IPOP framework, and did not find support for it using mobile technology.

Even if the level of control that the framework potentially affords is not yet at its peak and as the IPOP authors recognize, the research instrument employed to determine visitors' preferences requires fine tuning, there is value in applying the framework. Structuring the content and designing the user experience with the different dimensions in mind guided the development of a rich and human-centered tool, and contributed to a better appreciation of visitors' diversity, the same conclusion that other authors arrived at (Beghetto, 2014; Léger, 2014). As the analysis of all the study's variables revealed, the mobile app was utilized in a variety of ways and appealed to different visitor interest niches, even if they were not distributed according to IPOP dimensions.

Location was shown to play an important role in the experience with the case study mobile app. The visitor to the exhibition mainly used a phone rather than a tablet to browse the app and was visibly impaired by time constraints, social demands and the conditions of the environment as reflected by shorter app sessions and viewing of fewer pieces and shorter durations of content. Understandably, the offsite visitor revealed a greater attention span and more often experienced the app on a larger screen, which is a more pleasurable experience than on smaller screens. Museum app development should be mindful of these differences and design experiences with a primary use location in mind. Important decisions include screen size versus device portability, and amount, depth and duration of content. The bimodal in-gallery and offsite model of the case study mobile app extended the opportunity for engagement beyond the physical space of the exhibition, and facilitated different experiences according to the user location. Unless a museum is looking into providing an exclusive on-site experience to draw visitation in, or specifically wants to develop a tool that is external to its galleries, it seems advantageous to adopt a bimodal model and attentively consider the different settings that users might find themselves in when using the mobile tool.

Several other informative aspects were found about the adoption of mobile technology by museums to accompany an indoor exhibition, particularly when using AR technology. Concerns found in the literature of a potential detraction or replacement effect of the traditional museum experience promoted by AR or by the use of a mobile app were not supported. The case study app was highly appreciated by visitors, regarded as an enhancement to the exhibition and an improvement to their experience. Any skepticism against mobile technology or the established belief that using a mobile device in a museum exhibition induces a heads-down experience and disconnects the visitor from the surroundings was disproven by the use of AR technology. In fact, AR stimulated the opposite effect by strengthening the relationship between visitors and the objects on display.

What has been regarded as the greatest contribution of mobile technology to museums – introducing personalized, customizable and individual experiences (Stogner, 2009) that override the uniform experience facilitated by traditional audio tours – was strongly acknowledged by the visitors. Users of the mobile app appreciated a self-directed and paced visit where they made their own choices. This finding aligns with the results of other studies. Swift (2013), referring to the AR app developed for the Museum of London said "*we have found that people most value using technologies that enable them to take control of their learning and to personalize the way they engage with the history of the city."* (p.62). Also, users of the mobile app Creatures of Light at the American Museum of Natural History said "*goes at your own pace and you can go back and go deeper*" and "*I control the flow of information*" (Alonso & Hayward, 2013, p.41). Falk and Dierking (2008) went as far as saying that the physical context of a museum exhibition can only enhance the Visitor Experience if individuals can personally tailor the visit, which in a technology-enhanced context includes customizable mobile tools. The non-linear character of Skin & Bones and the prodigious offering of a variety of content maximized its flexibility and audience reach to a diverse audience, in terms of interests, providing opportunities for personalization so appreciated by the visitors.

Concerns about personalization of the visit contributing to a narrowing exposure to exhibits, and limiting the role of serendipitous discovery (Marty, 2007b) may hold partially true for the case study. Visitors using the mobile app were primarily guided through the space by the digital content. Nevertheless, in the absence of the mobile tool barely any discovery was taking place such was the lack of interest the exhibition was generating. Other environments, stimulating as they may be in the absence of technology may want to consider ways of promoting exposure and strategically delivering visitor options.

Although the great majority of visitors had never used AR technology, for the most part they were successful in activating it without any guidance beyond the on-screen instructions. They did not find the experience fatiguing although it requires holding the mobile device for the duration of content. Consistency in the process of triggering AR proved paramount as did eliminating any ambiguity concerning the target object. Factors influencing a successful onboarding were the scale of the object in relation to the surrounding objects, the position of the object in the display case and within the exhibition, and the distance between the user and the object. Careful planning of where in the exhibition the augmentation takes place and what activates it ensures the success of onboarding the augmented experiences, especially at medium or high visitation galleries.

Undoubtedly, the greatest hurdles found by visitors while using the case study mobile app were the internet connection and the noise in the gallery resulting from the crowds. Access to Wi-Fi was somewhat unreliable and unstable, and a large number of visitors were not aware that it was available as a complimentary service offered by the Museum. These are not uncommon problems and in other institutions that for one reason or another are not able to provide Wi-Fi additional problems exist. The recent European agreement of eliminating cell phone roaming charges by mid-2017 (European Commission, 2015) promises to alleviate the situation, at least for the later. Yet it will not resolve the bulk of the problems. Human facilitation, through docents and volunteers on the museum floor, is still the best guarantee of resolving connectivity issues, especially visitor awareness and assistance with getting online, besides being a valuable resource in troubleshooting mobile app operations. Some museums use this human resource method. For example, at the American Museum of Natural History one volunteer mans a cart on the floor, promoting and troubleshooting the mobile AR game MicroRangers, but the operational cost and management are not achievable to all institutions.

Audio in museum exhibitions is possibly the utmost challenge for BYOD mobile experiences, especially in large and overcrowded institutions. More reliance on visuals only and on written text are options but not without consequences to the visually impaired, and to those who do not appreciate or are not used to captioned text. At a time when museums show an interest in furthering experiments with audio in the galleries and its advocates consider the potential of creating soundscapes at large (Bubaris, 2014), perhaps new technical solutions of sound control will emerge. In the meantime, better crowd management with (free or paid) timed tickets is gaining popularity among blockbuster museums and exhibitions and museum professionals are forced to be creative with the resources at their disposal to ameliorate the obstacle.

For the advancement of cultural heritage, art, science and nature risk-taking with innovative technologies should be grounded on informed assessments of their true impact on museum visitors. This research brought insight into some of the contributions of AR technology to the Visitor Experience and the knowledge can be advanced in several ways. Namely a closer look into audiences might reveal finer differences in the acceptance, use and experience with the technology related to age, gender, educational level and other sociodemographic variables, some of which were already hinted at by findings presented here. Particularities of the case study and research setting narrowed the generalizations that analyses of such variables can have for other museums with different subjects and locations and conditions; more granular comparison studies would provide complementary and useful information. In addition, as with most museum studies, this research would have benefited from a follow up study with recruited visitors, some time after their participation. Although methodologically complex given the well-known low participation rates and required collection of personal data, such studies provide good assessments of the long-term influence of the museum visit. Specifically in the investigation of AR technology, checking back with participants could discern how much the novelty and uniqueness of the experience contributes to a lasting memory of the visit, and if the added connectedness with the exhibition makes a difference in visitors' relationship with the institution and the collection. Antiquated exhibitions reinvigorated through AR technology would naturally be desirable settings to replicate part of or the entire research methodology employed here for the interest of supporting the results and explore further ways of coexisting the aged exhibition with a new experience, the analog and the digital, the past and the future. Finally, given the potential that a successfully predictive human dimensions framework such as IPOP represents, other uses of the four-dimensional construct to design and structure the mobile digital space and analyze the correlation between visitors' preferences and behaviors is warranted.

This research concludes with a note looking into the future of AR technology in museums. AR was shown to be a serious and reliable technology at a maturity level that merits use by museum professionals with a confidence for enhancing the Visitor Experience. Its flexibility surpasses that of any other existing medium for the myriad creative ways in that image, sound, motion and interplay between real and virtual can be explored. At a time when collections are being scanned in 3D at an unprecedented rate and the production of virtual content is ever more accessible, imagination and storytelling skills should become the main focus for developing the relationship between onsite and offsite visitors and museum offerings. Although some current constraints should not be overlooked, namely cost, which determines access to expertise and technical and human resources, and a few impairing aspects of the museum physical environment, a greater embracing, development and study of the technology mediated experience can alleviate the problems. Considering the findings in this research the investment seems to be worthwhile. Predictions from industry, business and marketing firmly believe that

AR technology will revolutionize interaction with the world as we know it. Overstated as these predictions may be, museum professionals would do well by conceiving a future where visitors expect more than objects, labels and static graphics as the basis of their experience and augmentation is a primary tool to connect them with the physical exhibition, and where the physical and virtual are interwoven in meaningful ways that create memories for the memory seekers who visit museums.

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APPENDIX A: Data Collecting Protocol

Asking for participation

1) Research assistant selects visitors alternately at the mammal entrance to the Bone Hall and the fish entrance. After each visitor is processed, research assistant looks for the next visitor that appears to be interested in the exhibition (stops at display case, walks into the Bone Hall looking at skeletons above).

Exceptions: 1) visitor appears to be younger than 12; 2) visitor appears to be younger than 14 and is not accompanied by an adult; 3) visitor is part of organized group (indicated by matching t-shirts, badges around the neck, etc.) or coming in a very large family/friends group (more than 5 members); 4) visitor is the parent in a family group with small children (< 9 years old).

- The flow of visitors entering the Bone Hall is greater at the mammal room than at the fish room, making it more difficult to recruit to participate in the study at the later. However, it is important to sample visitors as much as possible on both sides of the exhibition.

- The Bone Hall can be very crowded and the flow of visitors so fast and steady that the recruiting process becomes impossible. If such conditions are observed, the research assistant should wait for the crowd to slow down.

- Due to the crowds entering the Bone Hall, recruiting visitors right at the entrance usually results in visitors declining or becoming impatient for blocking the traffic. A better recruiting location is inside the exhibition itself – at the mammal room next to the sign of Skin & Bones and at the fish room next to the Anglerfish case.

2) Research assistant approaches visitor and asks for participation using consent language (if visitor appears to be younger than 14 years-old, permission is asked of the visitor and the accompanying adult):

Good morning/afternoon, my name is –– (points at SI badge that needs to be visible at all times) and I am conducting a study here in the Museum. We have a new mobile app for this skeleton exhibit and are inviting the visitors to test it and give us feedback on their experience.

If you would like to participate I will hand you an iPad and you can use the app as much or as little as you want; you can stop at any time. I will be around the exhibit, following along, and when you're done just come see me. There is a 4-minute survey at the end I would ask you to fill in.

Would you like to participate?

2a) Visitor does not understand the question, showing signs of disability or difficulty with English. Research assistant thanks the visitor and adds entry to the Declined List[1], writing: date,

[1] The Declined List is printed and carried by the research assistant in every data collecting session. At the end of each session the information is entered digitally by the lead researcher.

time, “Disability” or “Language” under reason, age range (10-15, 15-20, 20-30, 30-40, 40-50, 50-60 or 60-70) and gender (F or M).

2b) If visitor declines, the research assistant adds entry to the Declined List, writing: date, time, reason for declining if stated, age range and gender.

- Common reasons for declining are 1) “Language” (visitors believe their English level is not good enough), 2) “Time” (visitors say they are in a rush because their time at the Museum is limited), 3) “Not Computer Oriented”, 4) “Looking for my group” (visitors walk in the Bone Hall to find their family/friends), 5) “Going for food/restroom”. When visitors decline and give no reason, research assistant enters “No, thank you” in the Declined List.

2c) If visitor accepts, research assistant opens Skin & Bones on iPad R1/R2[2] and enters in the pop up window the Identification Number (ID#)[3] for that participant. Previously the research assistant made sure that iPad R1/R2 is connected to the Wi-Fi network (si-visitor or si-staff). iPad R1/R2 is then handed to participant and research assistant steps back to let participant engage with the app.

- The study compares the visitor experience with two versions of Skin & Bones. Both are research versions that retrieve all user data, i.e., by connecting the iPad to the computer data regarding what content the visitor selected, in which order and for how long is downloaded. The two versions exist exclusively on the research iPads dedicated to the study (R1/R2). The data collection sessions alternate between using one version or the other.
  - AR-version is a replica of the production version available in the App Store
  - non-AR-version replaces all the Augmented Reality content by still images or animation videos.

- During the data collecting sessions where the non-AR-version is used, the signage in the Hall that promotes the app needs to be hidden: the stanchions should be turned against the wall, and the wall signs covered. The labels on the glass remain uncovered.

- During the data collecting sessions, research assistants aims to recreate as much as possible the scenario of visitors walking into the exhibition and downloading Skin & Bones independently. As such, the recruiting process should avoid any explanations about the app. If visitors ask directly for assistance, the research assistant should help but later eliminates the data point from the dataset.

[2] iPads R1 and R2 are used primarily to hand out to the visitors. With a big blue cover.
[3] There is a master list with Identification Numbers (ID#) that range from 001 and 999. Each new session assigns the first participant the next previously unused ID#. All participants remain anonymous and their ID# and Time Enter in the exhibition are the information that connects all data.

Observation and Tracking

At all times the research assistant carries iPad R3/R4[4] with the Track'n'Time app[5] installed. Once a visitor agrees to participate and starts using Skin & Bones, the research assistant begins the observation and tracking, using the app to record the data. It is very important to touch the Time Enter button in Track'n'Time as soon as the participant begins – the starting time of each participant is the primary way to connect the Time'n'Track data with the Skin & Bones data. iPad R3/R4 does not have to be connected to the Wi-Fi network to record the data.

The observation and tracking ends (and the Time Exit button is pressed) when the participant stops using Skin & Bones and meets the research assistant. While the participant is filling in the questionnaire, the research assistant enters data in the Track'n'Time Info tab: Crowd Level[6], Gender, Additional Notes (records the group structure – e.g., "with adult female partner and child" - and any other relevant information).

The research assistant tries at all times to guarantee the safety of iPad R1/R2. If participant attempts to leave the Bone Hall with the device, she should immediately be intercepted and asked for the device back.

- The pilot data indicates that participants stop mostly at cases featured in Skin & Bones but not necessarily all of them. The average time time of engagement is about 12 minutes but some participants spend as little as 4 minutes and others up to 45 minutes.

- It is important to find the balance between keeping distance from participants to not interfere with the visit and guarantee good observation spots to record their behavior.

- Some visitors agree to participate and later hand the iPad to another member of the group. This behavior is prevalent in multigenerational groups, with older visitors handing the device to children and teenagers. It is the primary person selecting the content and using the app who should fill in the questionnaire. A child may fill in the questionnaire if the adult consents and assists the procedure.

[4] iPads R3 and R4 are used primarily for observation and tracking. With a black cover.
[5] Track'n'Time app is a mobile app designed to do observation and tracking in museum exhibitions. A tutorial on using Track'n'Time follows this protocol.
[6] Crowd Level is an arbitrary measure with 3 levels: Low, Medium, High. Low=between 0 and 5 visitors in the mammal room; Medium=between 5 and 15 visitors in the mammal room; High=more than 15 visitors in the mammal room.

Filling in the questionnaire

Once the participant is ready to return the iPad and fill in the questionnaire, the research assistant takes the device, closes Skin & Bones, and opens the Safari browser. The online questionnaire is bookmarked. The research assistant fills in the ID# field before handing the iPad back to the participant.

- The research assistant needs to complete training for doing research with human subjects and be Smithsonian staff or Smithsonian affiliated with a sponsor.
- The lead research is responsible for extracting the data from iPads R1-R4 and for merging it with the questionnaire answers collected online by SurveyMonkey. Only an individual certified in human subject research can access and store the data.

Next: Track’n’Time Tutorial

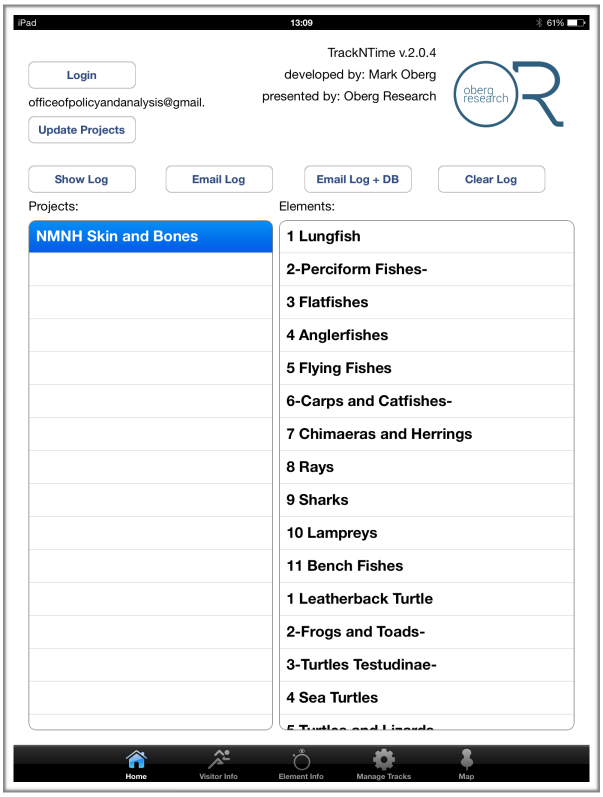
TRACK'N'TIME TUTORIAL FOR SKIN & BONES OBSERVATION AND TRACKING

For a generic video tutorial on using Track'n'Time on an iPad go to:
https://www.youtube.com/watch?v=FA4k06DNyLk&feature=youtu.be

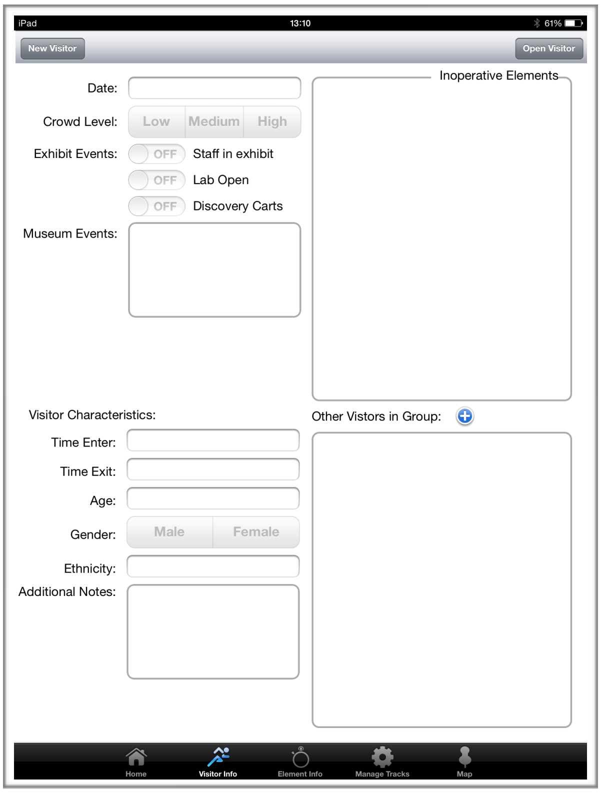
For directions on using Track'n'Time for the Skin & Bones study see below.

(1) Track'n'Time opens in the Home tab. At the column on the left the only project listed should be "NMNH Skin & Bones". To start using the app move to the Visitor Info tab.

(1)



(2)

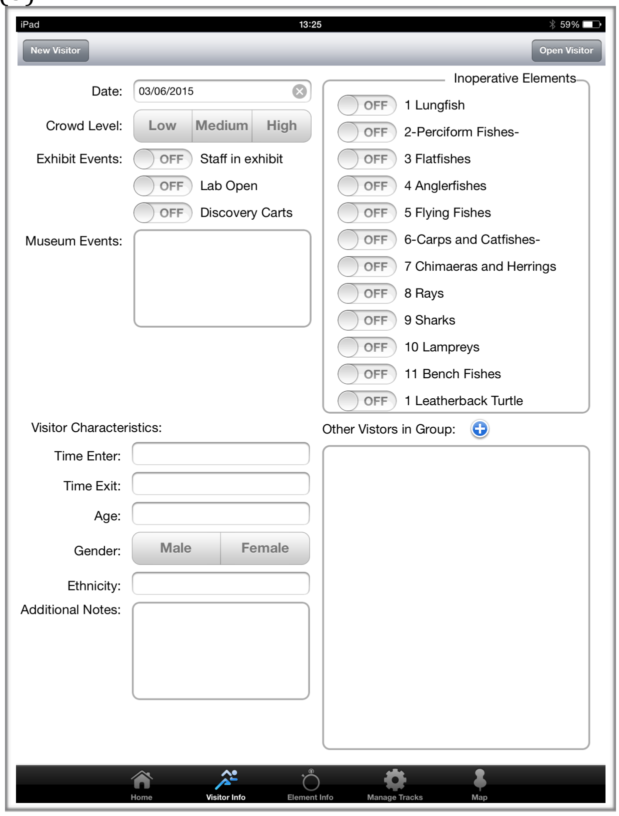


(2) At the Visitor Info tab select New Visitor (top left) and select the only project listed "NMNH Skin & Bones". Doing this will populate the Date field.

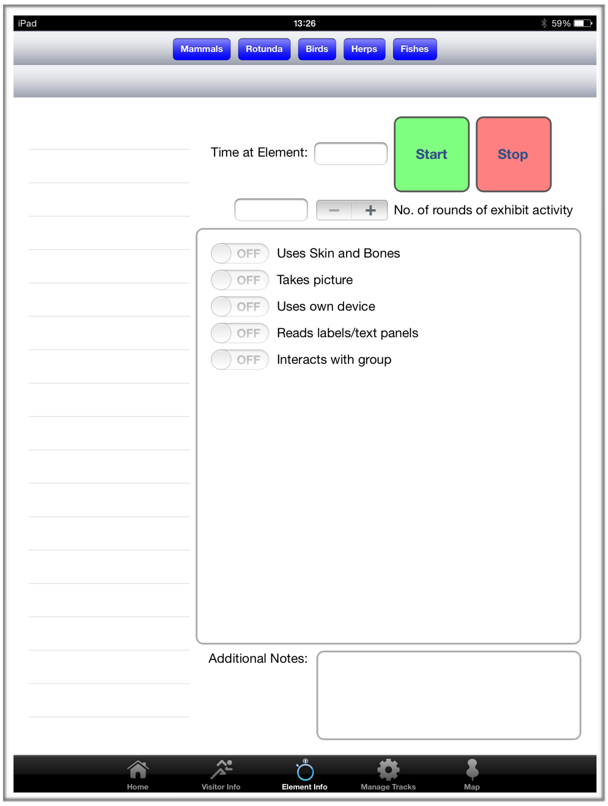
To start tracking a participant press the Time Enter field which records the current time; move right after to the Element Info tab to the participant's stop information. The remaining data – Crowd Level, Gender, Additional Notes – can be entered later. Disregard the fields: Exhibit Events, Museum Events, Age, Ethnicity and Other Visitors in Group **(3)**.

(4) At the Element Info tab select the room of the Bone Hall where the participant is. Doing this will populate the left column with a list of all the display cases for that room **(5)**.

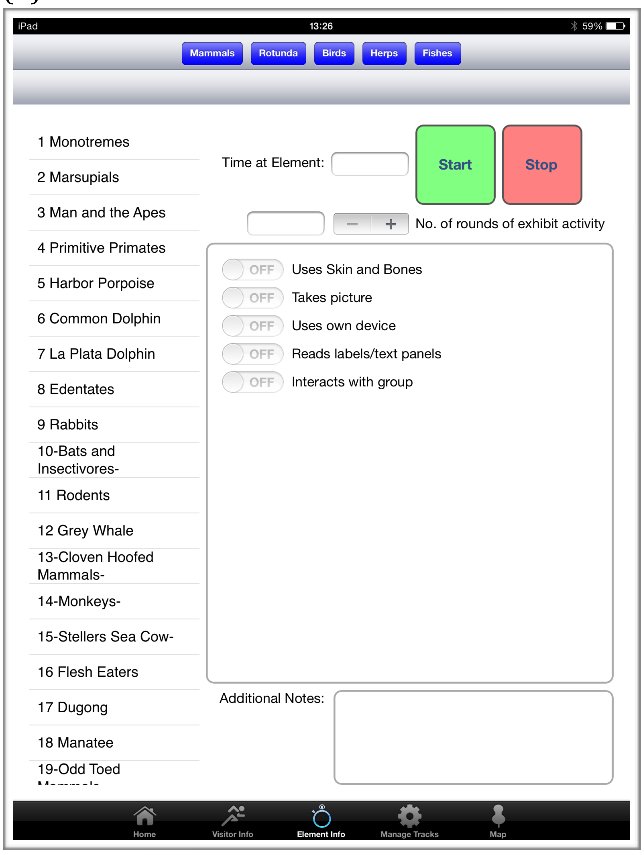
(3)


iPad
13:25
59%
New Visitor
Open Visitor
Date:
03/06/2015
Crowd Level:
Low
Medium
High
Exhibit Events:
OFF Staff in exhibit
OFF Lab Open
OFF Discovery Carts
Museum Events:
Inoperative Elements
OFF 1 Lungfish
OFF 2-Perciform Fishes-
OFF 3 Flatfishes
OFF 4 Anglerfishes
OFF 5 Flying Fishes
OFF 6-Carps and Catfishes-
OFF 7 Chimaeras and Herrings
OFF 8 Rays
OFF 9 Sharks
OFF 10 Lampreys
OFF 11 Bench Fishes
OFF 1 Leatherback Turtle
Visitor Characteristics:
Other Vistors in Group:
Time Enter:
Time Exit:
Age:
Gender:
Male
Female
Ethnicity:
Additional Notes:
Home
Visitor Info
Element Info
Manage Tracks
Map

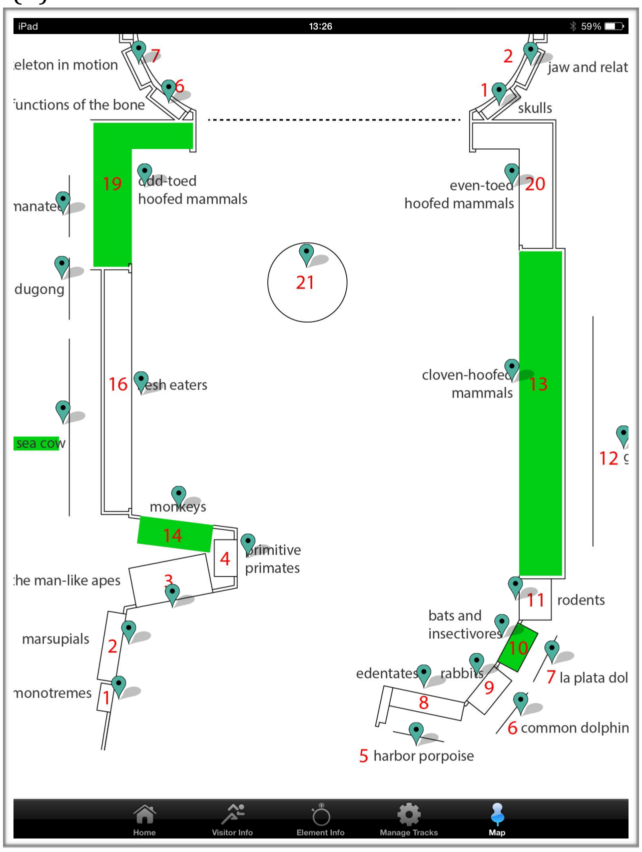
(4)


iPad
13:26
59%
Mammals
Rotunda
Birds
Herps
Fishes
Time at Element:
Start
Stop
No. of rounds of exhibit activity
OFF Uses Skin and Bones
OFF Takes picture
OFF Uses own device
OFF Reads labels/text panels
OFF Interacts with group
Additional Notes:
Home
Visitor Info
Element Info
Manage Tracks
Map

(5)


iPad
13:26
59%
Mammals
Rotunda
Birds
Herps
Fishes
1 Monotremes
2 Marsupials
3 Man and the Apes
4 Primitive Primates
5 Harbor Porpoise
6 Common Dolphin
7 La Plata Dolphin
8 Edentates
9 Rabbits
10-Bats and Insectivores-
11 Rodents
12 Grey Whale
13-Cloven Hoofed Mammals-
14-Monkeys-
15-Stellers Sea Cow-
16 Flesh Eaters
17 Dugong
18 Manatee
19-Odd Toed
Time at Element:
Start
Stop
No. of rounds of exhibit activity
OFF Uses Skin and Bones
OFF Takes picture
OFF Uses own device
OFF Reads labels/text panels
OFF Interacts with group
Additional Notes:
Home
Visitor Info
Element Info
Manage Tracks
Map

(6)


iPad
13:26
59%
eleton in motion
7
6
unctions of the bone
2
jaw and relat
1
skulls
19
odd-toed hoofed mammals
even-toed hoofed mammals
20
nanate
dugong
21
16
esh eaters
cloven-hoofed mammals
13
sea cow
12
monkeys
14
4
primitive primates
he man-like apes
3
11
rodents
bats and insectivores
marsupials
2
10
edentates
rabbits
7 la plata dol
9
monotremes
1
8
6 common dolphin
5 harbor porpoise
Home
Visitor Info
Element Info
Manage Tracks
Map

When a participant comes to a stop by a display case select the case from the list and press Start to activate the timer. Once the participant moves towards another case press Stop. Repeat the process for every stop. It's very important to press Start AND Stop – selecting another entry in the list before stopping the timer leads to exporting corrupted data.

If a participant comes to a halt away from a display case and stands using Skin & Bones, select "Standing" from the list. If she sits down at the benches in the mammal, bird or fish rooms select "Bench".

If one of the behaviors listed on the right column (and described below) is observed while the participant is in front of a display case, press the corresponding button. If the participant initially stops by a display case and later returns to it, select the corresponding case again from the list and the counter picks up where it left previously.

If a participant moves too fast and it becomes difficult to record the behavioral and stopping data, manually enter the information on the Additional Notes field.

The Map tab **(6)** is a labeled top view of the Bone Hall. Pressing the pin at a display case takes the user to the Element Info tab and to the room where the display case is; but it does NOT select the case from the list or start the counter, which needs to be done separately.

The exporting and deleting of tracks is done at the Manage Tracks tab. A track cannot be deleted unless it's exported first. In order to disregard a track recorded by mistake, make a note in the Additional Notes field and proceed with the data collection.

Behaviors

Group selection - the group accompanying the participant is observed making a collective decision regarding which display case to stop at or what Skin & Bones content to view

Talks about exhibit - the participant is observed gesticulating or pointing to discuss exhibition elements with her group. This behavior is recorded at any display case not just Skin & Bones stops.

Hands iPad to group - the participant hands the iPad to a member of her group and moves away to see other parts of the exhibition; it is different than sharing the viewing of the screen or having the other person hold the device for group viewing. Depending on the amount of time the iPad is not kept by the participant, the questionnaire should be administered to the other member of the group.

Calling others over - the participant calls for her group's attention; it is different than sharing the viewing of the screen, it involves moving towards the other members of the group and actively get them to go to a display case or view a piece of Skin & Bones content.

Takes picture - the participant takes a picture of a display case with her own camera/phone.

Reads labels/text panels - the participant is observed reading a text panel or label inside a display case.

App crash - if Skin & Bones crashes the participant may ask for assistance (in which case the ID# should be re-entered) or may reopen the app herself (in which case the data is later merged).

Could not operate AR - the participant tries to view AR content but is not successful. Common problems are: pointing the iPad to the wrong skeleton or wrong part of the display case; being confused about the intro video to the AR experience; being too close to the display case.

APPENDIX B: Questionnaire

SKIN & BONES

* ID# (filled in by the Researcher)

1. Have you been to this museum before?

- [ ] Yes
- [ ] No

2. Have you been to the Bone Hall before?

- [ ] Yes
- [ ] No

3. Please rate your overall experience in the Bone Hall today:

Poor	Fair	Good	Excellent	Superior
○	○	○	○	○

4. What brought you here today?

- [ ] I am on a general visit to the museum
- [ ] I came to the museum to use Skin & Bones
- [ ] I came to the museum to visit the Bone Hall
- [ ] I came to the museum for another reason and happened upon the Bone Hall

5. Who were you with in the Bone Hall today?

- [ ] I was alone
- [ ] I was with friends/family
- [ ] I was part of an organized group

6. Did the Bone Hall visit meet your expectations?

It was better than I expected	It was what I expected	It was not as good as I expected	I had no expectations
○	○	○	○

7. How comfortable are you with using mobile technology (e.g. smartphones or tablets) in museum exhibits?

I am comfortable	I am somewhat comfortable	I am neither comfortable nor uncomfortable	I am somewhat uncomfortable	I am uncomfortable
○	○	○	○	○

8. Will you download Skin & Bones to your own device (iPhone and/or iPad) after your visit?

☐ Yes

☐ No

☐ I would but I do not have an iPhone or iPad

9. Please rate your experience with Skin & Bones today:

Poor	Fair	Good	Excellent	Superior
○	○	○	○	○

10. Of the animals you saw in Skin & Bones, what was your favorite?

- ◯ Vampire Bat
- ◯ American Bison
- ◯ Mandrill
- ◯ Steller's Sea Cow
- ◯ Baird's Tapir
- ◯ Anhinga
- ◯ Pileated Woodpecker
- ◯ Kiwi
- ◯ South American Bullfrog
- ◯ Eastern Box Turtle
- ◯ Eastern Diamondback Rattlesnake
- ◯ Swordfish
- ◯ Blue Catfish

10.1) Why was it your favorite animal?

11) Of the sections you saw in Skin & Bones, what were your most and second favorite?

	Animal Life	Meet the Scientist	Skeleton Works	Big Idea	Activity
Most Favorite	◯	◯	◯	◯	◯
Second Favorite	◯	◯	◯	◯	◯

11.1) What is it about your most favorite that made you pick it?

12. Please tell us your level of agreement with the following items:

12.1) Skin & Bones made it easier for me to connect to the exhibit

Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
◯	◯	◯	◯	◯	◯	◯

12.2) Skin & Bones met my interest for knowing about the animals

Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
○	○	○	○	○	○	○

12.3) It was amazing to use Skin & Bones

Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
○	○	○	○	○	○	○

12.4) Skin & Bones did not hold my attention

Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
○	○	○	○	○	○	○

12.5) I do not want to share Skin & Bones with my friends

Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
○	○	○	○	○	○	○

12.6) Skin & Bones made me want to discover more about the animals

Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
○	○	○	○	○	○	○

For each of the following items, please indicate the degree to which that activity describes you.
I like to...

13.1) Bring people together

Not me at all	A little me	Me	Very much me
○	○	○	○

13.2) Construct things

Not me at all	A little me	Me	Very much me
○	○	○	○

13.3) Divide things into categories

Not me at all	A little me	Me	Very much me
○	○	○	○

13.4) Go camping

Not me at all	A little me	Me	Very much me
○	○	○	○

13.5) Help others in person

Not me at all	A little me	Me	Very much me
○	○	○	○

13.6) Identify patterns

Not me at all	A little me	Me	Very much me
○	○	○	○

13.7) Jog/run for fun

Not me at all	A little me	Me	Very much me
○	○	○	○

13.8) Know how things are made

Not me at all	A little me	Me	Very much me
○	○	○	○

13.9) Learn philosophy

Not me at all	A little me	Me	Very much me
○	○	○	○

13.10) Play competitive sports

Not me at all	A little me	Me	Very much me
○	○	○	○

13.11) Shop

Not me at all	A little me	Me	Very much me
○	○	○	○

13.12) Spend my leisure time with other people

Not me at all	A little me	Me	Very much me
○	○	○	○

14. Where do you live?

- [ ] DC Metropolitan Area
- [ ] US state
- [ ] Another country

15. In what year were you born?

16. What is the highest level of education you have completed?

- [ ] Less than high school
- [ ] High school graduate
- [ ] Some college (no degree)
- [ ] Associate/technical degree
- [ ] Bachelor's degree
- [ ] Graduate or professional degree

17. Which of the following best describes your ethnicity?

- [ ] American Indian or Alaska Native
- [ ] Asian Indian
- [ ] Black/African American
- [ ] Caucasian
- [ ] Chinese
- [ ] Filipino
- [ ] Hispanic
- [ ] Japanese
- [ ] Native Hawaiian
- [ ] Other Pacific Islander
- [ ] Other Asian
- [ ] Other

Thank you for completing the survey!

APPENDIX C: Cluster Analysis Results

Appendix C Table – Six participant clusters retained from the Hierarchical Cluster Analysis against the original variables used in the multivariate analysis. For each cluster is included the number of participants (#) in each variable category, and the percentage (row %) that number represents across all clusters. Higher percentages, highlighted in bold when participant count is above five, indicate the corresponding cluster had the highest number of participants for the variable category. Cluster 1 n=58; Cluster 2 n=30; Cluster 3 n=35; Cluster 4 n=32; Cluster 5 n=17; Cluster 6 n=27.

		Cluster 1		Cluster 2		Cluster 3		Cluster 4		Cluster 5		Cluster 6	
		#	row %	#	row %	#	row %	#	row %	#	row %	#	row %
AR Content Seen	Used-AR-Version and saw AR	5	6.7%	18	24%	26	**34.7%**	14	18.7%	6	8%	6	8%
	Used-AR-Version and did not see AR	15	**55.6%**	3	11.1%	3	11.1%	4	14.8%	0	0%	2	7.4%
	Used-non-AR-Version and saw AR-equivalent	25	**33.3%**	8	10.7%	5	6.7%	13	17.3%	11	14.7%	13	17.3%
	Used-non-AR-Version and did not see AR-equivalent	13	**59.1%**	1	4.5%	1	4.5%	1	4.5%	0	0%	6	27.3%
Been to Museum Before	Yes	22	27.5%	4	5%	13	16.3%	26	**32.5%**	11	13.8%	4	5%
	No	36	**30.5%**	26	22%	22	18.6%	6	5.1%	5	4.2%	23	19.5%
Been to Bone Hall Before	Yes	8	18.6%	0	0%	5	11.6%	19	**44.2%**	10	23.3%	1	2.3%
	No	48	**31.4%**	30	19.6%	29	19%	13	8.5%	7	4.6%	26	17%
Rating Experience Bone Hall	Superior	4	11.1%	5	13.9%	17	**47.2%**	1	2.8%	3	8.3%	6	16.7%
	Excellent	32	**27.8%**	17	14.8%	17	14.8%	18	15.7%	12	10.4%	19	16.5%
	Good	21	**46.7%**	7	15.6%	1	2.2%	13	28.9%	1	2.2%	2	4.4%
	Fair	0	0%	1	50%	0	0%	0	0%	1	50%	0	0%
	Poor	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%
Reason of the Visit	General visit to Museum	50	**29.2%**	26	15.2%	27	15.8%	31	18.1%	14	8.2%	23	13.5%
	Came to use Skin & Bones	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%
	Came to visit Bone Hall	1	25%	0	0%	0	0%	1	25%	0	0%	2	50%
	Came for another reason and saw Bone Hall	7	29.2%	4	16.7%	8	**33.3%**	0	0%	3	12.5%	2	8.3%
Group Structure	Alone	17	**37%**	1	2.2%	2	4.3%	11	23.9%	7	15.2%	8	17.4%
	With friends/family	41	**27.5%**	28	18.8%	32	21.5%	20	13.4%	10	6.7%	18	12.1%
	With organized group	0	0%	1	33.3%	1	33.3%	0	0%	0	0%	1	33.3%

(cont.)

Meeting of Expectations	No expectations	9	**28.1%**	6	18.8%	4	12.5%	3	9.4%	4	12.5%	6	18.8%
	Better than expected	23	23%	11	11%	24	**24%**	14	14%	12	12%	16	16%
	As expected	25	**41%**	10	16.4%	7	11.5%	13	21.3%	1	1.6%	5	8.2%
	Not as good as expected	1	16.7%	3	50%	0	0%	2	33.3%	0	0%	0	0%
Level of Comfort with Technology	Neither comfortable nor uncomfortable	3	**50%**	1	16.7%	0	0%	2	33.3%	0	0%	0	0%
	Comfortable	39	**26.2%**	22	14.8%	30	20.1%	20	13.4%	12	8.1%	26	17.4%
	Somewhat comfortable	12	**38.7%**	5	16.1%	4	12.9%	4	12.9%	5	16.1%	1	3.2%
	Somewhat uncomfortable	3	25%	2	16.7%	1	8.3%	6	**50%**	0	0%	0	0%
	Uncomfortable	1	100%	0	0%	0	0%	0	0%	0	0%	0	0%
Intention of Downloading Skin & Bones	Yes	17	22.7%	9	12%	20	**26.7%**	10	13.3%	5	6.7%	14	18.7%
	No	25	**35.2%**	8	11.3%	9	12.7%	13	18.3%	9	12.7%	7	9.9%
	Yes, but does not own Apple device	16	**31.4%**	11	21.6%	6	11.8%	9	17.6%	3	5.9%	6	11.8%
Rating Experience Skin & Bones	Superior	4	12.1%	5	15.2%	15	**45.5%**	0	0%	4	12.1%	5	15.2%
	Excellent	26	**26.8%**	14	14.4%	15	15.5%	15	15.5%	7	7.2%	20	20.6%
	Good	26	**44.1%**	10	16.9%	5	8.5%	12	20.3%	5	8.5%	1	1.7%
	Fair	2	22.2%	1	11.1%	0	0%	5	**55.6%**	1	11.1%	0	0%
	Poor	0	0%	0	0%	0	0%	0	0%	0	0%	1	100%
Favorite Section	Animal Life	34	**45.9%**	7	9.5%	3	4.1%	3	4.1%	4	5.4%	23	31.1%
	Meet the Scientist	3	50%	0	0%	0	0%	0	0%	3	50%	0	0%
	Skeleton Works	8	9.6%	18	21.7%	29	**34.9%**	22	26.5%	6	7.2%	0	0%
	Big Idea	12	**52.2%**	2	8.7%	0	0%	2	8.7%	3	13.0%	4	17.4%
	Activity	1	9.1%	2	18.2%	3	27.3%	4	36.4%	1	9.1%	0	0%
Easier to Connect to Exhibit	Strongly Disagree	0	0%	0	0%	0	0%	1	50%	0	0%	1	50%
	Disagree	4	57.1%	0	0%	0	0%	2	28.6%	1	14.3%	0	0%
	Somewhat Disagree	0	0%	0	0%	0	0%	1	50%	1	50%	0	0%
	Neutral	5	**41.7%**	3	25%	0	0%	4	33.3%	0	0%	0	0%
	Somewhat Agree	16	**40%**	8	20%	2	5%	12	30%	2	5%	0	0%
	Agree	25	**28.4%**	16	18.2%	18	20.5%	9	10.2%	5	5.7%	15	17%
	Strongly Agree	7	15.6%	3	6.7%	15	**33.3%**	2	4.4%	8	17.8%	10	22.2%

(cont.)

Met Interest for Animals	Strongly Disagree	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%
	Disagree	0	0%	1	33.3%	0	0%	2	66.7%	0	0%	0	0%
	Somewhat Disagree	2	66.7%	0	0%	0	0%	1	33.3%	0	0%	0	0%
	Neutral	1	11.1%	2	22.2%	0	0%	5	**55.6%**	1	11.1%	0	0%
	Somewhat Agree	14	**50%**	8	28.6%	1	3.6%	3	10.7%	2	7.1%	0	0%
	Agree	36	**32.1%**	15	13.4%	24	**21.4%**	17	15.2%	6	5.4%	14	12.5%
	Strongly Agree	5	11.9%	4	9.5%	9	21.4%	3	7.1%	8	19%	13	31%
Amazing to Use	Strongly Disagree	0	0%	0	0%	1	50%	1	50%	0	0%	0	0%
	Disagree	2	28.6%	0	0%	0	0%	5	**71.4%**	0	0%	0	0%
	Somewhat Disagree	3	60%	0	0%	0	0%	1	20%	1	20%	0	0%
	Neutral	12	**38.7%**	6	19.4%	0	0%	11	35.5%	1	3.2%	1	3.2%
	Somewhat Agree	23	**40.4%**	9	15.8%	5	8.8%	7	12.3%	7	12.3%	6	10.5%
	Agree	16	**26.7%**	8	13.3%	16	**26.7%**	3	5%	3	5%	14	23.3%
	Strongly Agree	2	5.6%	7	19.4%	13	**36.1%**	3	8.3%	5	13.9%	6	16.7%
Did not hold attention	Strongly Disagree	2	6.7%	6	20%	13	**43.3%**	1	3.3%	3	10%	5	16.7%
	Disagree	16	**25.4%**	10	15.9%	10	15.9%	5	7.9%	6	9.5%	16	**25.4%**
	Somewhat Disagree	5	**25%**	4	20%	2	10%	4	20%	2	10%	3	15%
	Neutral	8	**40%**	4	20%	0	0%	5	25%	2	10%	1	5%
	Somewhat Agree	17	**51.5%**	2	6.1%	3	9.1%	9	27.3%	2	6.1%	0	0%
	Agree	7	**30.4%**	3	13%	5	21.7%	6	26.1%	1	4.3%	1	4.3%
	Strongly Agree	3	37.5%	1	12.5%	2	25%	0	0%	1	12.5%	1	12.5%
Do Not Want to Share	Strongly Disagree	2	6.3%	4	12.5%	13	**40.6%**	2	6.3%	3	9.4%	8	25.%
	Disagree	18	**32.1%**	8	14.3%	10	17.9%	5	8.9%	4	7.1%	11	19.6%
	Somewhat Disagree	13	**40.6%**	7	21.9%	2	6.3%	3	9.4%	5	15.6%	2	6.3%
	Neutral	13	**35.1%**	6	16.2%	3	8.1%	10	27%	3	8.1%	2	5.4%
	Somewhat Agree	2	18.2%	2	18.2%	0	0%	6	**54.5%**	0	0%	1	9.1%
	Agree	9	**40.9%**	1	4.5%	5	22.7%	5	22.7%	0	0%	2	9.1%
	Strongly Agree	1	12.5%	2	25%	2	25%	0	0%	2	25%	1	12.5%

(cont.)

Want to Discover More	Strongly Disagree	0	0%	0	0%	1	50%	1	50%	0	0%	0	0%
	Disagree	2	50%	0	0%	0	0%	2	50%	0	0%	0	0%
	Somewhat Disagree	1	25%	2	50%	0	0%	1	25%	0	0%	0	0%
	Neutral	11	**33.3%**	8	24.2%	0	0%	9	27.3%	4	12.1%	1	3%
	Somewhat Agree	7	24.1%	6	20.7%	3	10.3%	9	**31%**	2	6.9%	2	6.9%
	Agree	30	**34.9%**	10	11.6%	20	23.3%	7	8.1%	4	4.7%	15	17.4%
	Strongly Agree	7	17.5%	4	10%	11	**27.5%**	2	5%	7	17.5%	9	22.5%
Main IPOP Dimension	Idea	12	**27.9%**	7	16.3%	11	25.6%	4	9.3%	4	9.3%	5	11.6%
	People	10	**32.3%**	1	3.2%	7	22.6%	6	19.4%	5	16.1%	2	6.5%
	Object	12	**36.4%**	4	12.1%	5	15.2%	6	18.2%	1	3%	5	15.2%
	Physical	8	24.2%	10	**30.3%**	2	6.1%	2	6.1%	2	6.1%	9	27.3%
	Multidimensional	12	**29.3%**	4	9.8%	4	9.8%	11	26.8%	5	12.2%	5	12.2%
Place of Origin	DC Metropolitan area	3	16.7%	2	11.1%	6	**33.3%**	2	11.1%	3	16.7%	2	11.1%
	US state	45	**31%**	20	13.8%	26	17.9%	23	15.9%	12	8.3%	19	13.1%
	Another country	10	**27.8%**	8	22.2%	3	8.3%	7	19.4%	2	5.6%	6	16.7%
Age	10-15	0	0%	13	**86.7%**	2	13.3%	0	0%	0	0%	0	0%
	16-20	4	14.3%	15	**53.6%**	5	17.9%	2	7.1%	0	0%	2	7.1%
	21-30	26	**39.4%**	0	0%	10	15.2%	15	22.7%	6	9.1%	9	13.6%
	31-40	11	**35.5%**	0	0%	7	22.6%	4	12.9%	4	12.9%	5	16.1%
	41-50	10	**40%**	0	0%	6	24%	5	20%	1	4%	3	12%
	51-60	1	14.3%	0	0%	0	0%	3	42.9%	2	28.6%	1	14.3%
	61-70	3	27.3%	0	0%	1	9.1%	0	0%	2	18.2%	5	**45.5%**
	71-80	0	0%	1	50%	0	0%	1	50%	0	0%	0	0%
Education Level	Less than high school	1	4%	21	**84%**	2	8%	1	4%	0	0%	0	0%
	High school	4	22.2%	7	**38.9%**	4	22.2%	0	0%	0	0%	3	16.7%
	Some college (no degree)	8	25.8%	2	6.5%	8	25.8%	9	**29%**	2	6.5%	2	6.5%
	Technical degree	3	37.5%	0	0%	1	12.5%	3	37.5%	1	12.5%	0	0%
	Bachelor degree	22	**37.3%**	0	0%	7	11.9%	11	18.6%	6	10.2%	13	22%
	Graduate/Professional degree	20	**34.5%**	0	0%	13	22.4%	8	13.8%	8	13.8%	9	15.5%

(cont.)

Ethnicity	American Indian/Alaska native	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%
	Asian Indian	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%
	Black/African American	0	0%	2	40%	3	60%	0	0%	0	0%	0	0%
	Caucasian	41	**27.9%**	22	15%	22	15%	23	15.6%	17	11.6%	22	15%
	Chinese	4	100%	0	0%	0	0%	0	0%	0	0%	0	0%
	Filipino	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%
	Hispanic	5	**38.5%**	0	0%	4	30.8%	3	23.1%	0	0%	1	7.7%
	Japanese	0	0%	0	0%	0	0%	0	0%	0	0%	1	100%
	Native Hawaiian	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%
	Other Pacific Island	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%
	Other Asian	1	100%	0	0%	0	0%	0	0%	0	0%	0	0%
	Other	6	**22.2%**	6	**22.2%**	6	**22.2%**	6	**22.2%**	0	0%	3	11.1%
Total Pieces of Content	0-2	7	30.4%	3	13%	5	21.7%	8	**34.8%**	0	0%	0	0%
	3-6	34	**44.2%**	8	10.4%	11	14.3%	18	23.4%	0	0%	6	7.8%
	7-10	9	22%	11	**26.8%**	5	12.2%	5	12.2%	1	2.4%	10	24.4%
	11-14	7	18.4%	4	10.5%	12	**31.6%**	1	2.6%	5	13.2%	9	23.7%
	>15	1	5%	4	20%	2	10%	0	0%	11	**55%**	2	10%
Number of Skeleton Works Pieces	0	31	**51.7%**	5	8.3%	4	6.7%	6	10%	0	0%	14	23.3%
	1-2	22	**33.3%**	7	10.6%	9	13.6%	14	21.2%	5	7.6%	9	13.6%
	3-4	4	12.5%	2	6.3%	7	21.9%	10	**31.3%**	5	15.6%	4	12.5%
	5-6	0	0%	8	**47.1%**	7	41.2%	0	0%	2	11.8%	0	0%
	7-8	1	4.2%	8	**33.3%**	8	**33.3%**	2	8.3%	5	20.8%	0	0%
Total Number of Videos	0	0	0%	5	20.8%	10	**41.7%**	9	37.5%	0	0%	0	0%
	1-2	13	25.5%	12	23.5%	7	13.7%	18	**35.3%**	0	0%	1	2%
	3-4	25	**49.0%**	6	11.8%	12	23.5%	4	7.8%	1	2%	3	5.9%
	5-6	13	**43.3%**	3	10%	5	16.7%	1	3.3%	1	3.3%	7	23.3%
	7-8	5	26.3%	1	5.3%	1	5.3%	0	0%	4	21.1%	8	**42.1%**
	9-10	1	12.5%	1	12.5%	0	0%	0	0%	2	25%	4	50%
	>11	1	6.3%	2	12.5%	0	0%	0	0%	9	**56.3%**	4	25%

(cont.)

Number of Animal Life Videos	0	2	5.6%	7	19.4%	13	**36.1%**	13	**36.1%**	1	2.8%	0	0%
	1-2	25	**31.3%**	17	21.3%	14	17.5%	19	23.8%	3	3.8%	2	2.5%
	3-4	23	**51.1%**	3	6.7%	8	17.8%	0	0%	2	4.4%	9	20%
	5-6	5	33.3%	0	0%	0	0%	0	0%	3	20%	7	46.7%
	7-8	1	11.1%	2	22.2%	0	0%	0	0%	3	33.3%	3	33.3%
	9-10	1	20%	1	20%	0	0%	0	0%	0	0%	3	60%
	>11	1	11.1%	0	0%	0	0%	0	0%	5	**55.6%**	3	33.3%
Number of Meet the Scientist Videos	0	31	**25.4%**	21	17.2%	26	21.3%	27	22.1%	2	1.6%	15	12.3%
	1-2	25	**37.9%**	8	12.1%	8	12.1%	5	7.6%	8	12.1%	12	18.2%
	3-4	2	28.6%	0	0%	1	14.3%	0	0%	4	57.1%	0	0%
	5-6	0	0%	0	0%	0	0%	0	0%	1	100%	0	0%
	7-8	0	0%	1	50%	0	0%	0	0%	1	50%	0	0%
	9-10	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%
	>11	0	0%	0	0%	0	0%	0	0%	1	100%	0	0%
Number of Big Idea Videos	0	35	**32.4%**	15	13.9%	23	21.3%	21	19.4%	1	0.9%	13	12%
	1-2	21	**28.8%**	13	17.8%	10	13.7%	9	12.3%	6	8.2%	14	19.2%
	2-3	2	14.3%	2	14.3%	2	14.3%	2	14.3%	6	**42.9%**	0	0%
	5-6	0	0%	0	0%	0	0%	0	0%	4	100%	0	0%
Number of Activities	0	48	**35.8%**	20	14.9%	19	14.2%	23	17.2%	2	1.5%	22	16.4%
	1-2	9	18%	6	12%	14	**28%**	6	12%	11	22%	4	8%
	3-4	1	6.7%	4	26.7%	2	13.3%	3	20%	4	26.7%	1	6.7%
Total Duration of Content (seconds)	4-60	8	**44.4%**	2	11.1%	2	11.1%	6	33.3%	0	0%	0	0%
	61-180	9	26.5%	4	11.8%	8	23.5%	13	**38.2%**	0	0%	0	0%
	181-300	14	**38.9%**	6	16.7%	5	13.9%	8	22.2%	0	0%	3	8.3%
	301-420	15	**60%**	3	12%	4	16.0%	3	12%	0	0%	0	0%
	421-540	5	31.3%	6	**37.5%**	2	12.5%	0	0%	1	6.3%	2	12.5%
	541-660	1	6.7%	5	33.3%	3	20%	0	0%	0	0%	6	**40%**
	661-780	1	11.1%	0	0%	3	33.3%	1	11.1%	0	0%	4	44.4%
	781-900	5	29.4%	0	0%	3	17.6%	0	0%	3	17.6%	6	**35.3%**
	901-1020	0	0%	0	0%	3	75%	0	0%	1	25%	0	0%
	1021-2040	0	0%	2	11.1%	1	5.6%	0	0%	9	**50%**	6	33.3%
	>2041	0	0%	1	25%	0	0%	0	0%	3	75%	0	0%

(cont.)

Duration of Skeleton Works pieces (seconds)	0	31	**51.7%**	5	8.3%	4	6.7%	6	10%	0	0%	14	23.3%
	4-60	22	**42.3%**	7	13.5%	2	3.8%	12	23.1%	3	5.8%	6	11.5%
	61-180	4	9.1%	6	13.6%	11	**25.%**	10	22.7%	6	13.6%	7	15.9%
	181-300	1	3.4%	7	24.1%	9	**31%**	4	13.8%	8	27.6%	0	0%
	301-420	0	0%	4	33.3%	8	66.7%	0	0%	0	0%	0	0%
	421-540	0	0%	1	100%	0	0%	0	0%	0	0%	0	0%
	541-660	0	0%	0	0%	1	100%	0	0%	0	0%	0	0%
Total Duration of Videos (seconds)	0	1	4.2%	4	16.7%	10	**41.7%**	9	37.5%	0	0%	0	0%
	4-60	9	28.1%	7	21.9%	5	15.6%	11	**34.4%**	0	0%	0	0%
	61-180	12	**27.9%**	10	23.3%	9	20.9%	11	25.6%	0	0%	1	2.3%
	181-300	16	**66.7%**	4	16.7%	2	8.3%	0	0%	0	0%	2	8.3%
	301-420	11	**61.1%**	1	5.6%	3	16.7%	0	0%	2	11.1%	1	5.6%
	421-540	3	21.4%	0	0%	4	28.6%	1	7.1%	1	7.1%	5	**35.7%**
	541-660	4	28.6%	1	7.1%	2	14.3%	0	0%	1	7.1%	6	**42.9%**
	661-780	1	10%	0	0%	0	0%	0	0%	4	40%	5	**50%**
	781-900	1	50%	0	0%	0	0%	0	0%	0	0%	1	50%
	901-1020	0	0%	0	0%	0	0%	0	0%	4	66.7%	2	33.3%
	1021-2040	0	0%	3	30%	0	0%	0	0%	3	30%	4	40%
	>2041	0	0%	0	0%	0	0%	0	0%	2	100%	0	0%
Duration of Animal Life Videos (seconds)	0	3	8.6%	5	14.3%	13	**37.1%**	13	**37.1%**	1	2.9%	0	0%
	4-60	15	**34.9%**	11	25.6%	5	11.6%	12	27.9%	0	0%	0	0%
	61-180	13	**30.2%**	10	23.3%	8	18.6%	7	16.3%	4	9.3%	1	2.3%
	181-300	17	**56.7%**	0	0%	7	23.3%	0	0%	1	3.3%	5	16.7%
	301-420	6	**46.2%**	0	0%	0	0%	0	0%	2	15.4%	5	38.5%
	421-540	1	6.7%	2	13.3%	2	13.3%	0	0%	3	20%	7	**46.7%**
	541-660	3	50%	1	16.7%	0	0%	0	0%	0	0%	2	33.3%
	661-780	0	0%	0	0%	0	0%	0	0%	4	66.7%	2	33.3%
	781-900	0	0%	0	0%	0	0%	0	0%	0	0%	1	100%
	901-1020	0	0%	1	50%	0	0%	0	0%	0	0%	1	50%
	1021-2040	0	0%	0	0%	0	0%	0	0%	2	40%	3	60%

(cont.)

Duration of Meet the Scientist Videos (seconds)	0	31	**25.2%**	21	17.1%	27	22%	27	22%	2	1.6%	15	12.2%
	4-60	17	**53.1%**	3	9.4%	3	9.4%	4	12.5%	3	9.4%	2	6.3%
	61-180	8	**25%**	4	12.5%	5	15.6%	1	3.1%	6	18.8%	8	**25%**
	181-300	2	40%	0	0%	0	0%	0	0%	1	20%	2	40%
	301-420	0	0%	1	33.3%	0	0%	0	0%	2	66.7%	0	0%
	421-540	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%
	541-660	0	0%	0	0%	0	0%	0	0%	1	100%	0	0%
	661-780	0	0%	1	100%	0	0%	0	0%	0	0%	0	0%
	781-900	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%
	901-1020	0	0%	0	0%	0	0%	0	0%	1	100%	0	0%
	1021-2040	0	0%	0	0%	0	0%	0	0%	1	100%	0	0%
Duration of Big Idea Videos (seconds)	0	35	**32.4%**	16	14.8%	23	21.3%	21	19.4%	1	0.9%	12	11.1%
	4-60	9	**29%**	0	0%	7	22.6%	9	**29%**	1	3.2%	5	16.1%
	61-180	11	30.6%	12	**33.3%**	1	2.8%	1	2.8%	7	19.4%	4	11.1%
	181-300	1	9.1%	0	0%	3	27.3%	0	0%	4	36.4%	3	27.3%
	301-420	2	28.6%	0	0%	1	14.3%	1	14.3%	0	0%	3	42.9%
	421-540	0	0%	1	50%	0	0%	0	0%	1	50%	0	0%
	541-660	0	0%	1	50%	0	0%	0	0%	1	50%	0	0%
	661-780	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%
	781-900	0	0%	0	0%	0	0%	0	0%	2	100%	0	0%
Duration of Activities (seconds)	0	48	**35.8%**	20	14.9%	19	14.2%	23	17.2%	2	1.5%	22	16.4%
	4-60	9	20%	7	15.6%	11	**24.4%**	6	13.3%	9	20%	3	6.7%
	61-120	0	0%	0	0%	1	25%	1	25%	1	25%	1	25%
	121-180	0	0%	3	100%	0	0%	0	0%	0	0%	0	0%
	181-240	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%
	241-300	0	0%	0	0%	0	0%	0	0%	1	100%	0	0%